patrick, Mrs. B. E. Longmire, A. C. Maddox, I. Maizlish, B. E. Mitchell, I. C. Nichols, Ralph L. O'Quinn, Amy F. Preston, W. D. Reeve, S. T. Sanders, H. E. Slaught, C. D. Smith, H. L. Smith, Ida K. Smith, P. K. Smith, N. Smylie, W. B. Stokes, Norma E. Touchstone, B. A. Tucker, Yetta Velinsky, J. F. Welch.

The guests of the section were H. E. Slaught, of Chicago; W. D. Reeve, of New York City; Marie Gugle and Amy F. Preston of Columbus, Ohio.

At the dinner tendered by the Chamber of Commerce of Shreveport and Centenary College, the principal address was given by Professor Slaught on the subject "Mathematics and sunshine." Professor Reeve gave an address at each of the regular sessions. The first dealt with the subject matter of "Junior high school mathematics"; the second was on the subject "What mastery should we expect in mathematics."

Miss Marie Gugle gave an illustrated lecture Saturday morning on the subject "Dynamic symmetry." Professor Roaten made a report on segregation of high school students on the basis of ability. One of the most interesting features of the meeting was a mathematical exhibit prepared by Professor Maizlish of Centenary College and Miss Preston of Columbus, Ohio. At the Saturday morning session, a branch of the National Council of Teachers of Mathematics was formed for the states of Louisiana and Mississippi, also a branch of the American Academy of Science.

Professor S. T. SANDERS was re-elected chairman of the section, Dean JOHN A. HARDIN vice-chairman for Louisiana and Professor HAL FOX for Mississippi. Professor P. K. SMITH of Mississippi Woman's College, Hattiesburg, Miss., was elected secretary-treasurer.

The following papers were read:

1. "Maximum efficiency in mathematical training," by Professor A. C. MADDOX, Louisiana State Normal College.

2. "Application of the exponential mean to Fourier's series," by Professor JULIA DALE, Delta State Teachers' College.

3. "Some applications of certain functional equations," by Professor I. MAIZLISH, Centenary College.

4. "A substitute for Duhamel's theorem," by Professor H. L. SMITH, of Louisiana State University.

Abstracts of the third and fourth papers are as follows:

3. The following four functional equations were discussed by Professor Maizlish:

$$g(x+y) = g(x) + g(y), \qquad g(xy) = g(x) + g(y),$$

$$g(x+y) = g(x)g(y), \qquad g(xy) = g(x)g(y).$$

Applications of these equations were made to certain problems in thermodynamics and the kinetic theory of gases. Among other things, a proof was given of the following interesting theorem: "A necessary and sufficient condition in order that a function $F(x, y, w, z)$ be invariant under any orthogonal transformation is that it be a function of the radius vector only; that is, that $F(x, y, w, z) = G(x^2+y^2+w^2+z^2)$."

4. Professor Smith gave various sets of conditions which are sufficient for the validity of the equality

$$\text{Lim} \sum_{r=1}^{n} \varphi(x_r, x_{r-1}) = \int_a^b f(x)\, dx,$$

where $a(=x_0) < x_1 < x_2 < \cdots < x_{n-1} < b(=x_n)$, and where the limit is taken with respect to the norm of the partition just indicated. The proof depends on a lemma which also yields the usual existence theorem for the Riemann integral. Applications were made to the fundamental theorem of the integral calculus and to the length of arc.

B. E. MITCHELL, *Secretary*

THE THIRD ANNUAL MEETING OF THE NEBRASKA SECTION

The third annual meeting of the Nebraska section of the Mathematical Association of America was held on May 6, 1927, at the University of Nebraska. Twenty-two persons were present including twelve members of the Association. The following program was presented:

1. "Functions which represent primes for almost all integral values of the variable" by O. C. COLLINS, University of Nebraska (By invitation).

2. "Solutions of quadratic congruences modulo a power of 2" by LAURENCE HAMPTON, University of Nebraska.

3. "On substitution groups" by F. L. WILMER, Omaha, Nebraska. (By title).

4. "The principle of cross-classification" by EVELYN HESSELTINE, University of Nebraska.

5. "Polynomials associated with those of Legendre" by Mrs. FLORENCE B. Young, University of Nebraska. (By invitation).

6. "Failures in freshman mathematics" by A. L. CANDY, University of Nebraska.

1. Mr. Collins showed that any algebraically prime function with integer coefficients will represent primes for all integer values of the variable except certain ones which can be expressed in terms of the coefficients in such a way that substitution in the function will yield an algebraically factorable quantity. Of these integer values of the variable, some are independent of the arithmetic

form of the coefficients, and functions exist which represent composite numbers for no other integer values of the variables.

2. Mr. Hampton discussed the solution of the quadratic congruence modulo a power of 2, and obtained a few novel results.

4. Miss Hesseltine gave a discussion of the principle of cross-classification and showed how many results of the theory of numbers may be brought under this principle.

5. Mrs. Young discussed the properties of polynomials arising from those of Legendre by repeated differentiation or integration.

6. Mr. Candy presented statistics covering several years, showing that from thirty to forty percent of students who register in the freshman courses in mathematics in the University of Nebraska failed to complete their course satisfactorily. Some withdrew in good standing, others withdrew because of delinquency, but the larger number remained in class to the end of the semester and fail to make a passing grade.

Officers elected for the year 1927–28 are: W. C. BRENKE, University of Nebraska, Chairman; ELLEN H. FRANKISH, North High School, Omaha, Secretary-Treasurer; H. C. FEEMSTER, York College, Member of Executive Committee.

ELLEN H. FRANKISH, *Secretary*

THE ELEVENTH ANNUAL MEETING OF THE KENTUCKY SECTION

The eleventh annual meeting of the Kentucky Section of the Mathematical Association was held May 14, 1927, at the University of Kentucky, Lexington, Kentucky. Dean P. P. Boyd presided at both sessions. Dinner was served at 12 o'clock in the University Cafeteria.

After a short business meeting Dean Boyd called attention to the December, 1927 meeting of the National Association at Nashville, Tennessee, and urged each member to be present at the meeting. Professor GUY STEVENSON of the University of Louisville was made chairman and Professor A. R. FEHN was made secretary-treasurer for the year 1927–1928. The section expressed its appreciation to Dean Boyd and the University of Kentucky for the hospitable reception and delightful dinner given to the attending members. There were twenty-five present including the following members of the Association: P. P. Boyd, J. L. Clayton, J. M. Davis, D. S. Dearman, A. R. Fehn, W. R. Hutcherson, Florence E. LeStourgeon, C. A. Maney, E. L. Rees, C. H. Richardson, Guy Stevenson, B. B. Vance.

Papers were presented on the program as follows, abstracts of most of these being given, numbered to correspond:

1. "Equivalence and classification of pairs of quadratic forms" by Miss MARY COOPER, University of Kentucky (by invitation).

2. "On the multiplication of sigma functions" by Professor C. H. RICHARDSON, Georgetown College.

3. "Congruences and complexes of line geometry" by Professor W. R. HUTCHERSON, Berea College.

4. "Expansions of the Neumann type in terms of products of Bessel functions" by Professor GUY STEVENSON, University of Louisville.

5. "On the trisection of an angle" by Professor A. R. FEHN, Centre College.

6. "On the use of formulas" by Professor E. L. REES, University of Kentucky.

7. "A new emphasis in teaching of freshman mathematics" by Professor C. A. MANEY, Transylvania College.

8. "Survey courses in mathematics" by Professor D. S. DEARMAN, Kentucky Wesleyan College.

9. "Sectioning in mathematics" by Professor J. M. DAVIS, University of Kentucky.

10. Business.

1. It is shown that if two pencils of quadratic forms have the same elementary divisors, then one pencil can be transformed into the other by means of linear substitutions. After the proof that there exists a pair of forms whose matrix has any preassigned invariant factors, Weierstrass's canonical pair of quadratic forms are introduced. The paper is concluded with a classification of pairs of ternary and quaternary quadratic forms.

2. Professor Richardson showed how the partition notation simplified the multiplication of sigma functions, particularly when applied to the expression $\sum x^a \cdot \sum x_i^b x_j^c x_l^d \cdots x_m^k$ when a is different from, as well as when a is equal to, $b, c, d, \cdots, k$.

3. This paper gave some general statements defining complexes and congruences. Then it was shown how two points $P(y_1y_2y_3y_4)$ and $P(z_1z_2z_3z_4)$, which determine a straight line, give rise to six line coordinates. Some properties of these coordinates were then shown and an analytic development of complexes and congruences was thus derived.

4. A generalization of the expansions of arbitrary analytic functions obtained by Neumann (*Theorie der Bessel'schen Funktionen*) and Gegenbauer (Wiener Sitzungsberichte (2), vol. 74. (1877), pp. 124–130) in terms of Bessel functions and products of Bessel functions. This paper extends the expansion theories of Neumann and Gegenbauer in four general directions: (1) the number of Bessel functions occurring as factors in the terms of the expansions is extended from 2 to any number n; (2) the order; and (3) the argument of each of the Bessel functions in the expansions is given a more general form;

and, finally, (4) the extension is made to the expansion of functions of several variables. Also, a relation between these expansions and those of Taylor and Laurent is obtained, and certain orthogonality properties are derived.

5. This paper (called forth by questions from some of the writer's students concerning a recent solution of the trisection of an angle by means of the straight edge and compasses) is based on theorems in L. E. Dickson's *Elementary Theory of Equations*.

6. In this paper it was shown how many of the so-called fundamental formulas of analytics and calculus could be dispensed with, with little or no inconvenience to the student.

7. The mathematics survey course as taught at Transylvania College is one of a group of survey courses in a nearly uniform freshman program of study. Selected applications of mathematics to the fields of the various sciences, engineering, and business, are developed as illustrations of the quantitative nature of the structure of modern civilization. Especial emphasis is given to the point of view that the combination of the experimental method with the quantitative thinking of mathematics constitutes the basis of scientific progress. Among the topics covered in a year's course of four semester-hours with sections meeting twice weekly are the following: (1) logarithms and applications; (2) portions of trigonometry with applications to surveying and statics; (3) simple notations of the calculus with applications to algebraic functions; the law of growth; velocity and acceleration; (4) graphical methods with applications to various functions, with use of logarithms and the calculus; (5) energy, its measure and applications.

8. This paper dealt with a description of a survey course in mathematics. This course was designed to meet the demands of two classes of students: (1). those who wish to obtain a knowledge of mathematical thought and the contributions of mathematics to the world but who do not have the time or inclination to give to the study of mathematics the time required of a student to obtain this knowledge; (2). those who wish a survey of the field before going into the study of the details, this to be followed by the traditional courses.

A. R. FEHN, *Secretary*

CERTAIN MATHEMATICAL QUESTIONS SUGGESTED BY THE TRUE-FALSE TEST

By HELEN M. WALKER, Teachers College, Columbia University

Although most of the difficulties encountered by the maker of the true-false examination[1] are psychological in their nature, yet there arise in this con-

[1] In the usual "true-false examination" the student is told to mark a set of statements in some specified manner, indicating whether he believes them to be true or false. He is generally instructed

nection a few questions which can be satisfactorily answered only after a mathematical analysis. The object of this paper is to propose several such questions, to answer them from the point of view of the theory of probability, and to offer the results of a set of two thousand spins of a coin as an empirical check on the theoretical results.[1]

1. *In a true-false test of n statements, if the order is determined wholly by chance, what is the probability that there will be at least one run of k or more consecutive statements all of which are "true"?*

As a matter of actual practice, these tests are not often written with long runs of similar answers and students are sometimes troubled when they find themselves recording what they think to be a suspiciously long string of answers all alike. Long runs facilitate the passing of information from one class to another if the test is to be used more than once, and there may be many other reasons for avoiding them, but it does not appear that they should be entirely excluded on the ground that they are theoretically improbable.

For the sake of clarity and brevity we shall restate the problem as follows: *An unbiased coin is spun on its edge n times, a plus sign is recorded for each showing of heads, and a minus sign is recorded for each showing of tails. What is the probability that there will be at least one run of k or more consecutive plus signs in the record?*

Let $p_{n,k}$ = the probability that there will be at least one run of k or more heads in a set of n throws. We shall then find a difference equation by means of which $p_{n,k}$ may be obtained from $p_{n-1,k}$.

A sequence of k heads may occur in the first $n-1$ spins or it may be completed on the nth spin, the two cases being mutually exclusive. The probability that a k-sequence shall occur in the first $n-1$ spins is $p_{n-1,k}$. In order that a sequence of k heads be completed on the nth spin, it is necessary that tails shall appear on the $(n-k)$th spin, that the following k spins shall exhibit heads, and that there shall be no k-sequence of heads in the first $(n-k-1)$ throws.

to place a plus sign to the left of each statement which he believes to be true without qualification, and a different specified symbol, either zero or a minus sign, to the left of each statement which he believes to be false, or to be true only under conditions other than those stated. The use of zero makes for ease and rapidity of scoring; the minus sign has certain other advantages. To phrase a satisfactory set of statements for such a test is a task requiring considerable skill. For a further discussion of the use of the true-false test and the technique of its construction, the following references are suggested: D. G. Paterson, *Preparation and Use of New-Type Examinations* (World Book Company); G. M. Ruch, *Improvement of the Written Examination* (Scott, Foresman and Company); Ben D. Wood, *Measurement in Higher Education* (World Book Company).

[1] One thousand of the spins were made by Miss Ada M. Beckey, a student in Teachers College, who also assisted in tabulating the empirical data and in computing the averages obtained from them. No trial was counted in which the coin did not actually spin on its edge. Miss Beckey used one coin and the writer used another. In spite of preliminary trials to discover bias in the coins, those selected were probably imperfect. Both showed a preference for heads, the mean numbers of heads per hundred spins being 50.2 and 52.2, with a final average of 51.2.

The probability for this situation is the product of the various probabilities, or $(1-p_{n-k-1,\,k})\ (1/2)^{k+1}$. Therefore

$$(1) \qquad p_{n,k} = a^{k+1} + p_{n-1,k} - a^{k+1}p_{n-k-1,k}, \text{ where } a = \tfrac{1}{2}.$$

Now for any k, we have
$p_{n,k}=0$ when n is less than k; $p_{k,k}=a^k=2a^{k+1}$; $p_{k+1,k}=3\ a^{k+1}$;
$p_{k+2,k}=4\ a^{k+1}$; $\cdots$; $p_{2k,k}=(k+2)\ a^{k+1}$; $p_{2k+1,k}=(k+3)a^{k+1}-2a^{2(k+1)}$; etc. This may be continued indefinitely. The number of terms in the expression for $p_{n,k}$ is increased by one whenever the number of throws is increased by $k+1$. Thus, when $n=3k+2$, a third term will appear in the expression; and when $n=rk+r-1$, the expression will consist of r terms, the sign of the last one being $(-1)^{r-1}$.

The general expression for $p_{n,k}$ may be discovered by writing down a succession of the probabilities for different n's for the same value of k, and then this

TABLE I.

$$\begin{aligned}
p_{4,4} &= 2a^5 \\
p_{5,4} &= 3a^5 \\
p_{6,4} &= 4a^5 \\
p_{7,4} &= 5a^5 \\
p_{8,4} &= 6a^5 \\
p_{9,4} &= 7a^5 - 2a^{10} \\
p_{10,4} &= 8a^5 - 5a^{10} \\
p_{11,4} &= 9a^5 - 9a^{10} \\
p_{12,4} &= 10a^5 - 14a^{10} \\
p_{13,4} &= 11a^5 - 20a^{10} \\
p_{14,4} &= 12a^5 - 27a^{10} + 2a^{15} \\
p_{15,4} &= 13a^5 - 35a^{10} + 7a^{15} \\
p_{16,4} &= 14a^5 - 44a^{10} + 16a^{15} \\
p_{17,4} &= 15a^5 - 54a^{10} + 30a^{15} \\
p_{18,4} &= 16a^5 - 65a^{10} + 50a^{15} \\
p_{19,4} &= 17a^5 - 77a^{10} + 77a^{15} - 2a^{20} \\
p_{20,4} &= 18a^5 - 90a^{10} + 112a^{15} - 9a^{20} \\
p_{21,4} &= 19a^5 - 104a^{10} + 156a^{15} - 25a^{20} \\
p_{22,4} &= 20a^5 - 119a^{10} + 210a^{15} - 55a^{20} \\
p_{23,4} &= 21a^5 - 135a^{10} + 275a^{15} - 105a^{20} \\
p_{24,4} &= 22a^5 - 152a^{10} + 352a^{15} - 182a^{20} + 2a^{25} \\
p_{25,4} &= 23a^5 - 170a^{10} + 442a^{15} - 294a^{20} + 11a^{25}
\end{aligned}$$

general formula may be established by mathematical induction first for n and then for k. Let $k=4$, and let $p_{n,4}$ be the probability of a sequence of four heads in n spins. Table I shows the successive probabilities for at least one sequence of four or more heads in n spins, as n increases from 4 to 25.

It is readily apparent that the numbers which form the coefficients of a^{k+1} are the first differences of the numbers which form the coefficients of $a^{2(k+1)}$, the second differences of the numbers which form the coefficients of $a^{3(k+1)}$, and so on. In the *Chart to Facilitate the Computation of* $p_{n,k}$, these coefficients have been rearranged to form a difference table. The first differences for any column are to be found in the column directly to the left of it. The general terms of the columns are:

Column I $\quad (s+1)$

Column II $\quad \dfrac{(s)\,(s+3)}{2!}$

Column III $\quad \dfrac{(s)\,(s+1)\,(s+5)}{3!}$

Column IV $\quad \dfrac{(s)\,(s+1)\,(s+2)(s+7)}{4!}$

Column V $\quad \dfrac{s(s+1)(s+2)(s+3)(s+9)}{5!}$

Column VI $\quad \dfrac{s(s+1)(s+2)(s+3)(s+4)(s+11)}{6!}$

. . . . . .

. . . . . .

Column r $\quad \dfrac{s(s+1)(s+2)\cdots(s+r-2)(s+2r-1)}{r!}$

These general terms were found by taking differences and applying the formula[1]

$$(2) \qquad u_n = u_0 + n\Delta u_0 + \frac{n(n-1)}{2!}\Delta^2 u_0 + \frac{n(n-1)(n-2)}{3!}\Delta^3 u_0 + \cdots$$

The *Chart to Facilitate the Computation of* $p_{n,k}$ was constructed from the numerical coefficients in Table I. The coefficients of a^5 are found in Column I; of a^{10} in Column II; of a^{5r} in Column r. The pth entry in the rth column is the sum of the first p numbers in the $(r-1)$st column, and thus the chart is a difference table with the customary order reversed. Once the chart is constructed,

[1] See Whittaker and Robinson, *The Calculus of Observations* (Blackie and Son, Ltd.), page 11, or Forsyth, *Introduction to the Mathematical Analysis of Statistics* (John Wiley and Sons), page 19.

CHART TO FACILITATE THE COMPUTATION OF $P_{n,k}$.

S	I	II	III	IV	V	VI	VII	VIII	IX
			n=25, k=8	n=25, k=7	n=25, k=6	n=25, k=5	n=25, k=4	n=25, k=3	n=25, k=2
1	2	2	2	2	2	2	2	2	2
2	3	5	7	9	11	13	15	17	19
3	4	9	16	25	36	49	64	81	100
4	5	14	30	55	91	140	204	285	385
5	6	20	50	105	196	336	540	825	1210
6	7	27	77	182	378	714	1254	2079	3289
7	8	35	112	294	672	1386	2640	4719	8008
8	9	44	156	450	1122	2508	5148	9867	17875
9	10	54	210	660	1782	4290	9438	19305	37180
10	11	65	275	935	2717	7007	16445	35750	72930
11	12	77	352	1287	4004	11011	27456	63206	
12	13	90	442	1729	5733	16744	44200		
13	14	104	546	2275	8008	24752	68952		
14	15	119	665	2940	10948	35700			
15	16	135	800	3740	14688	50388			
16	17	152	952	4692	19380	69768			
17	18	170	1122	5814	25194	94962			
18	19	189	1311	7125	32319				
19	20	209	1520	8645	40964				
20	21	230	1750	10395	51359				
21	22	252	2002	12397	63756				
22	23	275	2277	14674	78430				
23	24	299	2576	17250	95680				
24	25	324	2900	20150					
25	26	350	3250	23400					
26	27	377	3627	27027					
27	28	405	4032	31059					

it may be used to read off the equation for any $p_{n,k}$ without further computation. Since we have here reproduced but a small section of the chart, which is theoretically unlimited in extent, it can be used for small values of n only.

The general method of finding the equation for $p_{n,k}$ from the chart is as follows:

(1) Look in Column I for the number $(n-k+2)$. This will be the coefficient of the first term in the expression for $p_{n,k}$, that is, the coefficient of $(1/2)^{k+1}$.

(2) Locate the exact center of the rectangle in which this number stands, and through that point draw a line with a slope of $(k+1)$, "slope" being interpreted as on a graph in which the two variables have been plotted with different units of measure. As this line crosses Column II it selects the coefficient of the second term, as it crosses Column III it selects the coefficient of the third term, etc., and the expression for the probability may be written down at once.

The family of lines belonging to a single k is the set of parallels having a slope of $(k+1)$.

The family of lines belonging to a single n is the pencil of lines passing through the center of that rectangle in Column s for which $s=n+2$. The pencil of lines drawn in the chart is a part of the family for which $n=25$.

The formula for $p_{n,k}$ is found by ordinary induction to be as follows:

$$
\begin{aligned}
p_{n,k} = {} & [s+1]_{n-k+1}a^{k+1} - \left[\frac{s(s+3)}{2!}\right]_{n-2k} a^{2(k+1)} \\
& + \left[\frac{s(s+1)(s+5)}{3!}\right]_{n-3k-1} a^{3(k+1)} \\
& - \left[\frac{s(s+1)(s+2)(s+7)}{4!}\right]_{n-4k-2} a^{4(k+1)} \\
& + \left[\frac{s(s+1)(s+2)(s+3)(s+9)}{5!}\right]_{n-5k-3} a^{5(k+1)} + \cdots \\
& + (-1)^{r-1}\left[\frac{s(s+1)(s+2)(s+3)\cdots(s+r-2)(s+2r-1)}{r!}\right]_{n-rk-r+2} a^{r(k+1)}.
\end{aligned} \tag{3}
$$

In the expressions such as $[s+1]_{n-k+1}$, the quantity within the square brackets is the general term of the column; the subscript gives the value to be assigned to s for particular values of n and k. When these particular values are substituted for the quantities within the brackets, the resulting formula for $p_{n,k}$ is:

$$
\begin{aligned}
p_{n,k} = {} & (n-k+2)a^{k+1} - \frac{(n-2k)(n-2k+3)a^{2(k+1)}}{2!} \\
& + \frac{(n-3k-1)(n-3k)(n-3k+4)a^{3(k+1)}}{3!}
\end{aligned}
$$

$$(4)\qquad -\frac{(n-4k-2)(n-4k-1)(n-4k)(n-4k+5)a^{4(k+1)}}{4!}+\cdots$$
$$+(-1)^{r-1}\frac{(n-rk-r+2)(n-rk-r+3)\cdots(n-rk)(n-rk+r+1)a^{r(k+1)}}{r!}.$$

This formula may be established, with no unusual difficulties, by the method of mathematical induction, by making use of the difference equation (1).[1]

2. *What is the most probable distribution of any set of n questions as regards the number of k-sequences* $(k=1, 2, 3, 4, \cdots, n)$ *occurring in it?* If the order is due to chance alone, how many sequences of exactly k records of the same sign are to be expected, or, in other words, what is the most probable number of k-sequences in a set of n spins of a coin? Here we are considering runs of exactly k terms, not of k or more.

The probability that a k-sequence will begin on the first throw is $(1/2)^k$, since it is necessary that the $(k-1)$ next succeeding terms shall have the same sign as the first term, and the kth term shall have the opposite sign. The sign of the first term itself is immaterial. The probability that a k-sequence will begin on the $(n-k+1)$st term is also $(1/2)^k$, since here it is necessary that the preceding term shall have the opposite sign and the $(k-1)$ succeeding terms shall have the same sign. The probability of a k-sequence beginning on any of the $(n-k-1)$ remaining terms is $(1/2)^{k+1}$, since the $(k-1)$ terms immediately following the initial term of the sequence must agree in sign, while both the term immediately preceding it and the kth term following it must be of the opposite sign. Therefore the mathematical expectation of a k-sequence is approximately

$$(5)\qquad N_k=(1/2)^k+(1/2)^k+(n-k-1)(1/2)^{k+1}=(n+3-k)(1/2)^{k+1}.$$

This formula evidently contains some error, since the probabilities of runs beginning on different terms are not all mutually exclusive. If p_i is the probability of a run beginning on the ith row, then the complete formula[2] for N_k should be

[1] After this paper was written, my attention was called by Dr. M. H. Stone to a note by Cramér, *Sur quelques points du calcul des probabilités*, in the London Mathematical Society Proceedings, 2nd series, vol. 23 (1924–25) pages lviii–lx. Cramér says that the problem of having a sequence of white balls in the course of n drawings of balls from an urn containing black and white balls has been treated by De Moivre, Condorcet, and Laplace, and that they have given the recurrence formula

$$a_{n,\mu}=a_{n-1,\mu}+p^\mu q(1-a_{n-\mu-1,\mu}),$$

where $q=1-p$; and the generating function

$$F_\mu(x)=\sum_{n=0}^{\infty}\beta_{n,\mu}x^n=\frac{1-p^\mu x^\mu}{1-x+p^\mu q x^\mu},\quad \text{where } \beta_{n,\mu}=1-a_{n,\mu}.$$

Dr. Stone points out that formula (3) could have been reached by the method of generating functions.

[2] See Coolidge, *Introduction to Mathematical Probability* (Clarendon Press), page 23.

$$N_k = \sum_{i=1}^{n} p_i - \frac{1}{2!}\sum_{i,j=1}^{n} p_{ij} + \frac{1}{3!}\sum_{i,j,l=1}^{n} p_{ijl} - \cdots$$

of which only the first term has been used in the approximation just given. To find the magnitude of the error committed we will again make use of a difference equation.

If the formula by which N_k is computed is a correct one, then $\sum kN_k$, from $k=1$ to $k=n$, should be equal to n. The difference between n and this sum furnishes an expression for the error made in using this approximation. This error, it must be remembered, is distributed over the n terms, all of which are positive.

We shall now prove that $\sum kN_k$, from $k=1$ to $k=n$, is $n-n(1/2)^{n-1}$, and that therefore the error in the computation of any single N_k cannot be greater than $n(1/2)^{n-1}$.

$$\begin{aligned}
\sum_{k=1}^{n} kN_k &= \sum_{k=1}^{n} k(n+3-k)(1/2)^{k+1} \\
&= (n+3)\sum_{1}^{n} k(1/2)^{k+1} - \sum_{1}^{n} k^2(1/2)^{k+1} \\
&= \left[(n+3)\{-(1/2)^k(k+1)\} + (1/2)^k(k^2+2k+3)\right]_1^n \\
&= \left[(1/2)^k(k^2-nk-k-n)\right]_1^n \\
&= (1/2)^n(-2n) - (1/2)(-2n) \\
&= n - n(1/2)^{n-1}.*
\end{aligned}$$

The sum of the probabilities as given by formula (5) is slightly too small, but since all of the n probabilities making up the sum are positive, the error in any one cannot be greater than $n(1/2)^{n-1}$. This error is very small, even for relatively low values of n.

The most probable distribution of a set of 100 questions, or of 100 spins of a coin, as to the number of sequences occurring in it, is shown in Table II. Table III presents similar information for a set of 50 questions. The third line of Table II may be interpreted thus: Two thousand spins of a coin were divided into 20 sets of 100 spins each. In these 20 sets the average number of times that exactly three heads or exactly three tails appeared in sequence was 6.05. The theoretically most probable number of such sequences in 100 spins is 6.25. If there were 6.25 runs of three similar records that would account for 18.75 spins out of the total 100 spins.

* The summation is effected by parts, by use of the formula $\sum v_x\Delta u_x = u_xv_x - \sum u_{x+1}\Delta v_x$. To evaluate $\sum k(1/2)^{k+1}$, we let $k=v_x$ and $(1/2)^{k+1}=\Delta u_x$. Then $\Delta v_x=1$, and $u_x=-(1/2)^k$, and $u_{x+1}=-(1/2)^{k+1}$. $\sum k(1/2)^{k+1} = -k(1/2)^k + \sum(1/2)^{k+1}$. As a check on the correctness of the solution given above, we see that $f(k)=(1/2)^k\cdot(k^2-nk-k-n)$, $f(k+1)=(1/2)^{k+1}\cdot(k^2+k-nk-2n)$; and also that $f(k+1)-f(k)=k(1/2)^{k+1}(n-k+3)$.

The column headed *Theoretical value of* N_k gives the most probable distribution of 100 spins in regard to sequences, and indicates the amount of bunching which is most probable in a set of 100 true-false questions where the order is determined by chance alone. No wise maker of tests would attempt to conform slavishly to this theoretical distribution, yet he may be interested to know that the laws of chance would provide for the occurrence of a run of seven consecutive similar answers in about one out of every three tests of this length, and that about one in every ten such tests might have a sequence of nine similar answers. There is considerable reason to think that it may be psychologically desirable to arrange test questions in such a way that a reasonable number of runs occur. The chief objection to the use of long runs is probably the one previously stated, that they increase the ease with which one student may illicitly purvey information to another.

TABLE II

Number of k-sequences in a set of 100 spins.

k	Empirical results of 20 sets of spins.	Theoretical value of N_k.	$k \cdot N_k$
1	25.40	25.500	25.50
2	12.00	12.625	25.35
3	6.05	6.250	18.75
4	3.05	3.094	12.37
5	1.69	1.531	7.66
6	.65	.758	4.55
7	.30	.375	2.63
8	.55	.186	1.49
9	.15	.091	.81
10	.05	.045	.45
11	.00	.022	.24
12	.00	.011	.13
			$\sum_1^{12} kN_k = 99.93$

TABLE III

Number of k-sequences in a set of 50 spins.

k	Empirical results of 40 sets of spins.	Theoretical value of N_k.	$k \cdot N_k$
1	12.950	13.000	13.000
2	6.000	6.375	12.750
3	3.125	3.125	9.375
4	1.475	1.531	6.125
5	.850	.750	3.750
6	.325	.367	2.203
7	.125	.180	1.258
8	.225	.089	.703
9	.075	.043	.387
10	.025	.021	.210
			$\sum_1^{10} kN_k = 49.761$

The following conclusions do not contribute much that is new to the technique of constructing the true-false examination, but they serve to illustrate the way in which mathematical reasoning may be used to check or to verify conclusions based on experience.

3. *Should exactly half of the statements be true and exactly half false? If this is not necessary, by how much may the number of true statements deviate from* $(1/2)n$ *?* What is the probability that the number of heads appearing in n spins will deviate from $(1/2)n$ by a number whose absolute value is greater than t ?

There is an impression current among students who have become expert in the technique of passing true-false tests that half of the statements are to be of one sort and half of the other. Occasionally a student reports that he changed some of his answers because on counting he discovered that he had too many plus signs!

The probability that exactly r heads will appear in a set of n spins of an unbiased coin is

$$p = \frac{n!}{r!(n-r)!}(1/2)^n, \tag{6}$$

which, by reasoning that is familiar to all students of probability, is a maximum when r is the integer nearest to $(1/2)n$. Therefore the most probable number of true statements, if that number is to be determined by chance alone, is $(1/2)n$. Formula (6) is the general term of the expansion $[(1/2)+(1/2)]^n$, and the standard deviation of this series is $(1/2)\sqrt{n}$. Thus the chances are roughly two to one that the number of true statements should be between the limits $(1/2)n \pm (1/2)\sqrt{n}$. The numerical values of these limits for a few selected values of n are shown in Table IV.

TABLE IV

n=number of questions	25	49	64	100
$\frac{1}{2}n$=mean number of questions	12.5	24.5	32	50
$\sigma=(1/2)\sqrt{n}$	2.5	3.5	4	5
Mean$\pm\sigma$	10–15	21–28	28–36	45–55
Mean$\pm$p. e.	10.8–14.2	22.1–26.9	29.3–34.7	46.6–53.4

4. *How should the test be scored? Is it better to use the total number of right answers as the score, or the difference between the number right and the number wrong? Should the students be encouraged to guess at answers they do not know?*

For reasons of a non-mathematical nature it is now generally conceded that it is better to use the difference between the number right and the number wrong rather than the number right and that guessing should be discouraged. These are not primarily mathematical questions, yet several mathematical considerations may be noted.

(a) *If all the questions in a test are answered, there is perfect correlation between the scores obtained by the two methods.*

Let A_i=number of correct responses made by a given pupil; B_i=number of incorrect responses made by the same pupil; t=number of questions in the test; N=number of pupils; $\bar{A}=\sum A/N$, or average number of correct responses; $a_i=A_i-\bar{A}$; $\sigma_a=\sum a^2/N$; let $\bar{B}$, b_i, and σ_b have meanings similar to those for $\bar{A}$, a_i, and σ_a. Let $A_i+B_i=t$; then $a_i+b_i=0$, $a_i-b_i=2a_i$. Let r_{ab}=coefficient

of correlation between A and B and $r_{a(a-b)}$ = coefficient of correlation between A and $(A-B)$. Then by the Pearson product-moment method[1] of computing a coefficient of correlation, we have

$$r_{a(a-b)} = \frac{\Sigma a(a-b)}{N\sigma_a\sigma_{a-b}} = \frac{\Sigma a(2a)}{N\sigma_a\sigma_{2a}} = \frac{2\sigma_a^2}{2\sigma_a^2} = 1.$$

Thus there is perfect correlation between the number right and the result of subtracting the number wrong from the number right if all the questions are answered, that is if $A_i+B_i=t$. If, however, some of the statements are left without a mark, then the correlation between the two forms of scores is probably not perfect, and the method of marking becomes an important matter.

(b) *If all the questions are answered, the standard deviation of the scores is twice as great when the number of wrongs is subtracted from the number of rights as when the number of rights alone is used.* If the results of several tests are to be combined or compared, the same method of scoring ought to be used for all.[2]

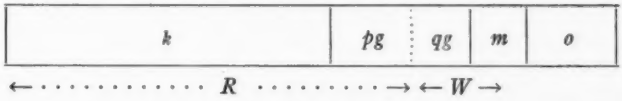
When $B=t-A$, it follows by the simplest of algebra that $\sigma_b=\sigma_a$, and that $r_{at}=-1$.

Then

$$\sigma^2_{(a-b)} = \sigma_a^2 - 2r_{ab}\sigma_a\sigma_b + \sigma_b^2 = 4\sigma_a^2, \quad \text{or} \quad \sigma_{(a-b)} = 2\sigma_a.$$

(c) *The practice of guessing reduces the amount of dependence which can be placed on the results of the tests.* This statement merely reiterates the outcome of thoughtful observation, yet the instructions accompanying true-false tests frequently tell the student to "be sure to mark every question, whether you are certain of the answer or not."

Let k = the number of questions whose answer a given student knows completely; m = the number of questions about which he is misinformed, so that he will, without much hesitation, set down the wrong answer, o = the number he omits; g = the number at which he guesses; pg = the number at which he guesses



successfully; and qg = the number at which he guesses unsuccessfully. The total number of right answers is $R=k+pg$. The total number of wrong

[1] The meaning and method of computing a coefficient of correlation, as well as the meaning of the standard deviation (σ), are discussed in almost every text on statistics. The reader is also referred to two papers which have appeared in this Monthly: E. V. Huntington *Mathematics and statistics, with an elementary account of the correlation coefficient and the correlation ratio*, vol. 26 (Dec. 1919), pp. 421–435; Dunham Jackson *The algebra of correlation*, vol. 31 (1924), pp. 110–121.

[2] This last statement obviously does not apply when the test scores are given weights in inverse proportion to their standard deviations.

answers is $W=m+qg$. If the student guesses, his score is $k+pg$ or $k-m+(p-q)g$. If he does not guess at all, his score is k or $k-m$. It is highly probable that p is greater than q, for even in unfamiliar material there are usually enough clues coming from the form of the questions and from one's general stock of information to make the chances for a correct answer somewhat better than for an incorrect one. If guessing is encouraged, therefore, the average score of the class is likely to be raised but the individual scores become less reliable, as will be shown.

Let us suppose that for a particular student in a particular test, k and m are fixed quantities. The uncertain element in his score arises from his chance marking of g. The most probable number of these questions to be marked correctly is pg, where p is some function of the student's general familiarity with the material, his degree of intelligence, the clarity with which the questions are phrased, and numerous other factors. It is almost certain that p varies from question to question, and the assumption made here of a p constant throughout the test is not altogether satisfactory. Moreover, while k and m may be constant and definite for a particular test, they are anything but that when we think of this test as a sample from the general subject matter with which the test deals.

$$\sigma_{k+pg} = \sigma_{pg} = (pqg)^{1/2} \leqq \tfrac{1}{2}(g)^{1/2}.$$

$$\sigma^2_{k-m+pg-qg} = \sigma^2_{(p-q)g} = \sigma^2_{pg} + \sigma^2_{qg} - 2r_{pg.qg}\sigma_{pg}\sigma_{qg} = 4\sigma^2_{pg}.$$

Therefore

$$\sigma_{k-m+pg-qg} = 2\sigma_{k+pg} = 2\sigma_{pg} = 2(pq)^{1/2}g^{1/2} \leqq g^{1/2}.$$

Thus for any particular set of questions the uncertainty as to a student's correct score decreases with a decrease in g, the number of questions at whose answer he guesses. If this area can be reduced by instructions which do not encourage guessing, the scores become increasingly more reliable.[1]

Without more data than is offered by the test itself, it is impossible to measure the amount of this fluctuation, because it is impossible to tell how many of the wrong answers belong to category g, and because it is impossible to get an *a priori* estimate of the size of p. No attempt is made here even to suggest the probable value of p, which may change from test to test, from pupil to pupil, and even from question to question. This would of course be an important consideration in deciding upon the method of scoring, since the optimum value of the constant t in the formula, $Score=R+tW$, is dependent upon the value

[1] This discussion of the uncertainty of a student's score does not take into account at all the unreliability that is due to sampling in the choice of test material. That is an entirely different matter. For a discussion of this, see Kelley, *The reliability of test scores*, Journal of Educational Research, vol. 3 (May, 1921).

of p. The value of t is probably between 0 and -1, and its "best" value for any given test could be determined statistically without great difficulty.

We can, however, set a maximum limit to the amount of fluctuation in pg, because we know that pq is a maximum when $p=q=1/2$.

$$\sigma_{pg} = (pqg)^{1/2} = p^{1/2}(qg)^{1/2} \leqq p^{1/2}(qg+m)^{1/2} = p^{1/2}W^{1/2} < W^{1/2};$$

$$\sigma_{pg} < W^{1/2} \text{ and } \sigma_{R-W} < 2(W)^{1/2}.$$

As an illustration, suppose that in a test of 100 statements, 5 are left unmarked and 25 are marked incorrectly. Then $R=70$. $R-W=70-25=45$. The standard deviation of $R-W$ is not greater than $2\sqrt{25}$, or 10. Thus the chances are better than 2 to 1 that the score should lie between 35 and 55; but how much better than 2 to 1 we cannot determine from this data.

TABLE V.

Rights		Rights minus wrongs.	
Score	Frequency	Score	Frequency
39	1	−22	1
40	0	−20	0
41	2	−18	2
42	0	−16	0
43	3	−14	3
44	0	−12	0
45	0	−10	0
46	0	− 8	0
47	3	− 6	3
48	0	− 4	0
49	1	− 2	1
50	1	0	1
51	1	2	1
52	1	4	1
53	1	6	1
54	3	8	3
55	0	10	0
56	1	12	1
57	0	14	0
58	0	16	0
59	2	18	2
Mean=49.1		Mean=−1.8	
σ=5.92		σ= 11.85	

For corroborating evidence, the results of the coin-spinning experiment have been again invoked. The two thousand records were divided into twenty sets of one hundred each, each set being considered as the answers to a true-false test. An additional hundred spins were made to furnish a "key" against which the other "tests" were scored. The results are shown in Table V. Theoretically, if the coin is unbiased, we should expect a mean score of 50 rights, with $\sigma=5$, σ of the mean $=0.5$, and σ of $\sigma=0.35$. When scoring rights minus wrongs, we should expect a mean value of 0, $\sigma=10$, σ of the mean $=1$, and σ of $\sigma=0.71$. The empirical results recorded in Table V are possible, but not highly probable from the theoretical point of view. Even for these figures the inequality $\sigma_{pg}=\sigma_R<\sqrt{W}$ seems to be a generous limit. For a score of 59, which is the highest in the list, this would make $\sigma<\sqrt{41}$, which is a limit considerably larger than 5.92.

ON A PROBLEM ARISING OUT OF THE THEORY OF A CERTAIN GAME[1]

By J. V. USPENSKY, Carleton College

The mathematical theory of a certain game[2] requires the solution of the following problem:

Is it possible to find n positive numbers $a, b, c, \cdots, l$ *in such a way that n series*

$$\begin{array}{lcccccc}
(A) & [a], & [2a], & [3a], & [4a], & \cdots \\
(B) & [b], & [2b], & [3b], & [4b], & \cdots \\
(C) & [c], & [2c], & [3c], & [4c], & \cdots \\
 & \cdot & \cdot & \cdot & \cdot & \\
 & \cdot & \cdot & \cdot & \cdot & \\
 & \cdot & \cdot & \cdot & \cdot & \\
(L) & [l], & [2l], & [3l], & [4l], & \cdots
\end{array}$$

reproduce, without repetition, the series of natural numbers $1, 2, 3, 4, \cdots$*?* Note: The symbol $[k]$ denotes the largest integer which is less than or equal to k.

The final answer to this question is very simple: namely, excluding the trivial case $n=1$, $a=1$, the problem is possible only when $n=2$, and then a and b must be irrational numbers satisfying the condition: $1/a+1/b=1$.

But the proof of this simple result requires somewhat elaborate analysis, based to a large extent on the following well known theorem due to Kronecker: *Denoting by* $a_1, a_2, \cdots, a_k$ *and* $b_1, b_2, \cdots, b_k$ *real numbers, it is possible to find integers* $x_0, x_1, x_2, \cdots, x_k$ *satisfying the system of inequalities*

$$\left|x_1 - a_1x_0 - b_1\right| < \epsilon\,; \quad \left|x_2 - a_2x_0 - b_2\right| < \epsilon, \cdots; \quad \left|x_k - a_kx_0 - b_k\right| < \epsilon,$$

where the positive number ϵ *may be taken arbitrarily small, provided integers* $\lambda_0, \lambda_1, \lambda_2, \cdots, \lambda_k$*, not all zero do not exist, so that*

$$\lambda_0 + \lambda_1a_1 + \lambda_2a_2 + \cdots + \lambda_ka_k = 0.$$[3]

In the first place it is easy to establish certain necessary conditions which should be fulfilled if the series $(A), (B), \cdots, (L)$ satisfy the requirements of our problem.

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[1] Read before the Minnesota Section of the Association, May 21, 1927.

[2] This game is described in Ahrens' book *Mathematische Unterhaltungen und Spiele* as Wythof's game.

[3] Kronecker, "*Näherungsweise ganzzahlige Auflösung linearer Gleichungen*, Kronecker's Werke, Bd. III, pp. 47–109.

Consider the totality of numbers of all these series which do not exceed an arbitrary positive integer N. As all these numbers are supposed to be different and as all other numbers of the series $(A), (B), \cdots, (L)$ are greater than N, it follows that they represent in their totality exactly the numbers $1, 2, 3, \cdots, N$. Now, the number of all the terms in the series (A) which do not exceed N is obviously given by the *greatest* integer m, satisfying the condition $[ma] \leqq N$, whence the following expression for m can be easily derived:

$$m = (N/a) + \epsilon \text{ where } -1 < \epsilon < 1/a.$$

In the same way we find the following expressions for the number of terms, not exceeding N, in the series $(B), (C), \cdots, (L)$ respectively:

$$n = \frac{N}{b} + \eta \text{ where } -1 < \eta < \frac{1}{b};$$

$$p = \frac{N}{c} + \zeta, \text{ where } -1 < \zeta < \frac{1}{c}; \cdots; \quad w = \frac{N}{l} + \omega, \text{ where } -1 < \omega < \frac{1}{l}.$$

From the preceding we conclude that the sum $m+n+p+\cdots+w$ is exactly equal to N, that is

$$N(1/a + 1/b + \cdots + 1/l) + \Omega = N \tag{1}$$

where

$$\Omega = \epsilon + \eta + \zeta + \cdots + \omega.$$

Now this number Ω may vary only within the finite limits

$$-n \text{ and } 1/a + 1/b + \cdots + 1/l;$$

dividing therefore both sides of the equation (1) by N and making N increase indefinitely we find that the numbers $a, b, c, \cdots, l$ must satisfy the exact relation:

$$1/a + 1/b + 1/c + \cdots + 1/l = 1. \tag{2}$$

This is the first necessary condition the numbers $a, b, c, \cdots, l$ must satisfy.

The second necessary condition is that not all these numbers are rational. For, supposing them all rational, we can represent them as fractions with the same denominator

$$a = p/s, \; b = q/s, \cdots l = u/s.$$

Let M be the least common multiple of $p, q, \cdots, u$; it is obvious that the following terms in the series $(A), (B), \cdots, (L)$ represent one and the same number:

$$\left[\frac{sM}{p}a\right] = M, \quad \left[\frac{sM}{q}b\right] = M, \cdots, \quad \left[\frac{sM}{u}l\right] = M,$$

which is contrary to our hypothesis. One, at least, of the numbers $a, b, \cdots, l$ must be irrational; let it be a. Let us introduce the abbreviated notation $1/a=\alpha$ and correspondingly $1/b=\beta$, $1/c=\gamma, \cdots, 1/l=\lambda$. By Kronecker's theorem we conclude the existence of integers m, n, k satisfying the inequalities

$$|m - k\alpha - \alpha/2| < \epsilon \tag{3}$$

$$|n - k\beta - \beta/2| < \epsilon \tag{4}$$

for an arbitrary small ϵ, *unless* β *and* α *are connected by the equation*

$$\beta = s - r\alpha \tag{5}$$

with certain *rational* s and r. By taking $\epsilon<\alpha/2$ and $\epsilon<\beta/2$ the inequalities (3) and (4) imply the following two,

$$k\alpha < m < k\alpha + \alpha, \quad k\beta < n < k\beta + \beta,$$

which are equivalent to

$$k < ma < k + 1, \quad k < nb < k + 1.$$

That is

$$[ma] = [nb] \tag{6}$$

while neither of the numbers ma, nb is an integer.

For positive k the numbers m and n are also positive, and from (6) we conclude the existence of two equal terms in series (A) and (B) respectively, contrary to our hypothesis. For negative k both m and n are negative, and from (6) it follows that

$$[-ma] = [-nb], \tag{7}$$

owing to the fact that neither of the numbers ma, nb is an integer. The equation (7) leads to the same contradiction as before. It is therefore necessary that α and β be connected by the equation (5).

Now we shall prove that $z>0$. Denoting by v the common denominator of the fractions z and s we can find positive integers k' and m' satisfying the inequality $0<m'-k'\alpha<\epsilon/v$ with arbitrary small ϵ (because α is an irrational number) whence, putting $m'v=m$, $k'v=k$, it follows that

$$k\alpha = m - \theta, \quad 0 < \theta < \epsilon. \tag{8}$$

From the equation (5) we get

$$k\beta = ks - mr + r\theta, \tag{9}$$

and $ks-mr=n$ is an *integer*. Supposing $r\leqq 0$ and taking $\epsilon<\alpha$, $|r|\epsilon<\beta$, from (8) and (9) we conclude

$$k\alpha < m < k\alpha + \alpha, \quad k\beta \leqq n < k\beta + \beta$$

or

$$k < ma < k + 1, \quad k \leqq nb < k + 1.$$

That is $[ma] = [nb]$, contrary to hypothesis. Therefore, $r > 0$.

As to the number s, we can prove that $s \leqq 1$. Suppose, on the contrary, $s > 1$ and denote by ϵ a positive number satisfying the inequalities

$$3\epsilon < (s-1)/r, \quad 3\epsilon < \beta/r. \tag{10}$$

By Kronecker's theorem it is possible to find integers k', m' satisfying the inequality

$$|m' - k'\alpha - gv^{-1}| < \epsilon v^{-1}, \quad g = \alpha - r^{-1}(s-1) + 2\epsilon$$

whence, for $k = k'v$, $m = m'v$, it follows that $|m - k\alpha - g| < \epsilon$; that is

$$\theta = m - k\alpha = g + \nu\epsilon\,; \quad -1 < \nu < 1. \tag{11}$$

At the same time we have

$$k\beta = n - (1 - r\theta), \quad \text{where} \quad n = ks - mr + 1 \quad \text{is an integer.}$$

As $\theta < g + \epsilon = \alpha - r^{-1}(s-1) + 3\epsilon$ and ϵ satisfies the first of the inequalities (10), it follows that $\theta < \alpha$. On the other hand

$$\theta > \alpha - \tfrac{1}{2}(s-1) + \epsilon = r^{-1}(1-\beta) + \epsilon > 0$$

because $\beta < 1$, as can be easily seen from (2). As $0 < \theta < \alpha$, we derive from (11)

$$[ma] = k. \tag{12}$$

Considering the number $1 - r\theta$ we find first

$$1 - r\theta > 1 - r[\alpha - r^{-1}(s-1) + 3\epsilon] = \beta - 3\epsilon r > 0$$

because of the second of the inequalities (10), and second

$$1 - r\theta < 1 - r[\alpha - r^{-1}(s-1) + \epsilon] = \beta - \epsilon r < \beta,$$

whence we can conclude $[nb] = k$ and further, comparing this with (12)

$$[ma] = [nb] \quad \text{and at the same time} \quad [-ma] = [-nb].$$

That is, we reach again the same contradiction as before, and therefore we must assume $s \leqq 1$.

Now we can express α in terms of β in the following way: $\alpha = sr^{-1} - \beta r^{-1}$, and as β proves to be an irrational number we can reason as before and obtain the important inequality

$$s/r \leqq 1 \text{ or } s \leqq r.$$

Applying the same reasoning to couples of numbers $\gamma, \alpha; \delta, \alpha; \cdots$, we finally reach the conclusion: All the numbers $\alpha, \beta, \gamma, \cdots$, are irrational and connected by the equations

$$
\begin{aligned}
&\beta = s - r\alpha\,; && s \leqq r, && r > 0\\
&\gamma = s' - r'\alpha\,; && s' \leqq r', && r' > 0\\
&\delta = s'' - r''\alpha\,; && s'' \leqq r'', && r'' > 0\\
&\cdots\cdots\cdots\cdots\cdots\cdots\\
&\cdots\cdots\cdots\cdots\cdots\cdots
\end{aligned}
\tag{13}
$$

Now we have the equation (2) $\alpha+\beta+\gamma+\cdots+\lambda=1$, and if we substitute here for $\beta, \gamma, \delta, \cdots$, their expressions (13) we get

$$s + s' + s'' + \cdots - 1 = (r + r' + r'' + \cdots - 1)\alpha,$$

whence, α being an irrational number, it follows necessarily that

$$s + s' + s'' + \cdots = 1 \text{ and } r + r' + r'' + \cdots = 1$$

and this necessitates

$$s = r, \quad s' = r', \quad s'' = r'', \cdots$$

because

$$s \leqq r, \quad s' \leqq r', \quad s'' \leqq r'', \cdots$$

On the other hand, if $n \geqq 3$ we have $r < 1$. The fact that $s = r$ is of fundamental importance; it shows that β is connected with α by the equation $\beta = s(1-\alpha)$ and, interchanging β and α, we have an equation of the same kind,

$$\alpha = \sigma(1 - \beta) \text{ or } \beta = 1 - (\alpha/\sigma).$$

Comparing this expression with the preceding we get

$$1 - (\alpha/\sigma) = s - s\alpha, \text{ whence } s = \sigma = 1.$$

That is $r = 1$. This shows that in case $n \geqq 3$ we reach the contradiction with the inequality $r < 1$ and therefore we have to admit that $n \leqq 2$. Now if $n = 1$ we have a trivial case $a = 1$, but in case $n = 2$ we find that the numbers a and b, both *irrational*, must satisfy the equation $1/a + 1/b = 1$. This necessary condition is at the same time sufficient.

To prove this we only need to establish the following two statements:

(i). For a given m it is impossible to satisfy simultaneously the two inequalities

$$m\alpha < k < m\alpha + \alpha, \qquad m\beta < l < m\beta + \beta$$

by integers k and l. For, adding these inequalities and taking into account that $\alpha + \beta = 1$ we get

$$m < k + l < m + 1$$

which is impossible.

(ii). If it is impossible to satisfy the inequality $m\alpha < k < m\alpha + \alpha$ by an integer k, then it is possible to find an integer l satisfying the inequality $m\beta < l < m\beta + \beta$. In this case it is possible to find an integer k by the conditions $m\alpha + \alpha < k < m\alpha + 1$.

Now introduce for α an equal number $1 - \beta$, which gives $m\beta < m + 1 - k < m\beta + \beta$ and it is obvious that the inequality $m\beta < l < m\beta + \beta$ is satisfied by taking $l = m + 1 - k$, which completes the proof of our theorem.

TSCHIRNHAUS TRANSFORMATIONS ON CERTAIN RATIONAL CUBICS

By RAYMOND GARVER, University of Rochester

1. Introduction. Any rational, algebraic transformation on the roots of an equation of the nth degree can be reduced to an integral transformation of degree[1] less than or equal to $(n-1)$. Such transformations were first studied by Tschirnhaus in the seventeenth century and are named for him.[2] Simple examples are found in the transformations of the elementary theory of equations. Thus a preliminary linear transformation on the roots of any cubic equation can be employed to remove the second term; hence we shall consider the rational cubic only in the form

$$f(x) = x^3 + a_2 x + a_3 = 0, \quad (a_2 \text{ and } a_3 \text{ rational}) \tag{1}$$

which has its discriminant $D = -4a_2^3 - 27a_3^2$.

The most general Tschirnhaus transformation on the roots of (1) can be expressed as

$$y = m(x^2 + k_2 x + k_3) = P(x), \tag{2}$$

where m, k_2, k_3 are real or complex numbers and $m \neq 0$. In most of our work we take $m = 1$. Transformation (2) leads to a new equation in y, whose second coefficient will be zero provided

$$\Sigma y = m(\Sigma x^2 + k_2 \Sigma x + 3k_3) = m(s_2 + k_2 s_1 + 3k_3) \tag{3}$$

is equal to zero, where $\sum x^k$ means the sum of the kth powers of the roots of (1) and is denoted by s_k.

However, for equation (1) we have

$$s_1 = 0, \; s_2 = -2a_2, \; s_3 = -3a_3, \; s_4 = -2a_2^2, \; s_5 = 5a_2 a_3, \tag{4}$$
$$s_6 = -2a_2^3 + 3a_3^2.$$

The condition $\sum y = 0$ therefore gives

$$k_3 = 2a_2/3. \tag{5}$$

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[1] Dickson, *Modern Algebraic Theories*, p. 211.

[2] Tschirnhaus, Acta Eruditorum, vol. 2 (1683), pp. 204–207.

If we square both sides of (2), sum over the roots of (1), and substitute from (4) and (5), we obtain

$$\Sigma y^2 = m^2[(2/3)a_2^2 - 2k_2^2 a_2 - 6k_2 a_3], \tag{6}$$

and similarly

$$\Sigma y^3 = m^3[3a_3^2 + (2/9)a_2^3 + 3k_2 a_2 a_3 + 2k_2^2 a_2^2 - 3k_2^3 a_3]. \tag{7}$$

The coefficient of y in the transformed equation will be $-(\sum y^2)/2$, and the constant term will be $-(\sum y^3)/3$.

2. **Reduction to Binomial Form.** Tschirnhaus first reduced the general cubic, which can be taken in form (1), to the binomial form $y^3+n=0$, by a method similar to, though more laborious than, the one employed here.[1] This binomial form can be secured by setting $\sum y^2=0$, solving the resulting quadratic in k_2, and computing $\sum y^3$ for one of these values of k_2. We obtain, after reducing (7) to a linear expression in k_2 by using $\sum y^2=0$, and then substituting

$$k_2 = [-9a_3 \pm (-3D)^{1/2}]/6a_2,$$

the following convenient form:

$$\Sigma y^3 = (1/54)Dm^3 a_2^{-3}[3D \pm 9a_3(-3D)^{1/2}]. \tag{7'}$$

The constant term of the transformed equation is then

$$(1/54)Dm^3 a_2^{-3}[-D \mp 3a_3(-3D)^{1/2}],$$

which can be made rational for any cubic of type (1) if we allow m to have complex values. It will, on the other hand, be irrational, in general, if we consider only transformations with rational coefficients. In this connection we state

THEOREM I. *A necessary and sufficient condition that a rational cubic* $x^3+a_2x+a_3=0$ *be transformable by a rational Tschirnhaus transformation into* $y^3+R=0$, *where* R *is rational and different from zero, is that it be of the form*

$$x^3 + 3crm^2x + m^3(c^3r - r^2) = 0 \quad (m, c, r \text{ rational}). \tag{8}$$

PROOF: First, the condition is sufficient. For if to (8) we apply the transformation $y=x^2-mc^2x+2crm^2$, where k_2 and k_3 are selected as indicated above, (using the negative sign in the selection of k_2), we obtain the transformed equation

$$y^3 - r[m^2(c^3 + r)]^3 = 0, \tag{10}$$

which is of the desired form.

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[1] Tschirnhaus eliminated x between (1) and (2), and then chose the parameters to obtain the form $y^3+n=0$. The *method* of Article 1–2 has been used by a number of writers but the actual results are believed to be new.

Conversely, suppose that a cubic in x is transformed into

$$y^3 + r = 0. \tag{11}$$

The most general Tschirnhaus transformation on (11) which gives a transformed equation of type (1) is easily seen to be $x=m(y^2+cy)$, and the transformed equation is exactly equation (8), except that here we cannot say definitely that m and c must be rational—they might be irrational, and yet the coefficients in (8) be rational.

We now state a lemma, which is given in a more general case as an exercise in L. E. Dickson's *Modern Algebraic Theories*, page 211:

LEMMA. *If the roots of the transformed equation in y (in the form (11) for example) are distinct, then the roots of the original equation in x can be expressed in the form $x_i=r(y_i)$, where $r(z)$ is a rational function of z whose coefficients are derived rationally from those of the $f(x)$ and $P(x)$.*[1]

For the greatest common divisor $d_i(x)$ of $f(x)$ and $P(x)-y_i$ $(i=1, 2, 3)$ is found by rational operations, so that its coefficients are rational functions of y_i whose coefficients are derived rationally from those of $f(x)$ and $P(x)$. Since both $f(x)$ and $P(x)-y_i$ vanish for $x=x_i$, we have $d_i(x_i)=0$, and $d_i(x)$ is of at least the first degree in x. And it cannot be of higher than the first degree. For x_1, x_2, x_3 are distinct, since $y_1=P(x_1)$, $y_2=P(x_2)$, $y_3=P(x_3)$ are distinct, and $d_i(x)$ would necessarily vanish for two distinct roots of $f(x)=0$, say x_i and x_j. Since $d_i(x)$ is a factor of $P(x)-y_i$, the latter vanishes both for $x=x_i$ and $x=x_j$. That is, $y_j \equiv P(x_j)=y_i$, contrary to hypothesis. Hence $d_i(x)$ is of the first degree.

The G. C. D. process, applied to $f(x)$ and $P(x)-y_i$, will give eventually a divisor of the first degree in x, which, by the lemma, is the G. C. D. This divisor is

$$x(a_2 - k_3 + y_i + k_2^2) + (a_3 + k_2k_3 - k_2y_i).$$

Since it vanishes for $x=x_i$, we have

$$x_i = (k_2y_i - a_3 - k_2k_3)/(y_i + a_2 + k_2^2 - k_3), \tag{12}$$

which can be considered as a transformation leading from the equation in y back to the equation in x. Also we know (see Section 1) that it is equivalent to an integral transformation, of which the coefficients must be rational. This follows since the coefficients in (12), considered as a rational function of y, are rational by hypothesis (though the lemma is obviously valid when this is not the case), and since the process of replacing a rational transformation by the equivalent integral transformation involves only rational operations.[2] Hence the given equation is one which can be obtained from (11) by a Tschirnhaus

[1] $f(x)$ and $P(x)$ are defined by (1) and (2).

[2] See L. E. Dickson, *Modern Algebraic Theories*, p. 211 and p. 151.

transformation, and it is, therefore, after its second term has been removed, of the form (8).

Example. The equation $x^3+6x-2=0$ is of the form (8) with $m=1$, $c=1$, $r=2$. From (10), the transformed equation is at once seen to be $y^3-54=0$. Equation (12) gives $x_i=(6-y_i)/(3+y_i)$, and corresponding to the root $y_1=3\cdot 2^{1/3}$ of $y^3-54=0$ we secure $x_1=(2-2^{1/3})/(1+2^{1/3})$ as a root of the given equation.

3. Reduction to Form $y^3=0$. The lemma of the preceding section, and the argument dependent on it, clearly do not apply if the r of (11) is zero, since the roots of the transformed equation are no longer distinct. We have, however:

THEOREM II. *A necessary and sufficient condition that a rational cubic $x^3+a_2x+a_3=0$ be transformable into $y^3=0$ is that it have a double root.*

PROOF: If we have an equation of the given type transformed by $y=m(x^2+k_2x+k_3)$ into $y^3=0$, we must have $y_i=m(x_i^2+k_2x_i+k_3)=0$ for $i=1, 2, 3$, so that x_1, x_2, x_3 cannot be distinct. Conversely, if the equation $x^3+a_2x+a_3=0$ has a double root, the transformation $y=x^2-(3/2)a_3a_2^{-1}x+(2/3)a_2$, which in general gives the equation $y^3+(1/12)a_2^{-1}Dy-(1/216)a_2^{-3}D^2=0$, clearly leads to $y^3=0$ in this case.

4. A Transformation on Cyclic Cubics. Every cubic with rational coefficients whose Galois group for the field of rational numbers is the cyclic group can be reduced to the form[1] $z^3-3(m^2+m+1)z+(m^2+m+1)(2m+1)=0$, or, setting $2m+1=p$ and $x=2z$, to the form

$$x^3-3(p^2+3)x+2p(p^2+3)=0. \tag{13}$$

That is, for the cyclic cubic (13) $a_2=-3(p^2+3)$, $a_3=2p(p^2+3)$, and the discriminant is easily calculated to be $18^2(p^2+3)^2$. If we now apply transformation (2), $\sum y^2=0$ has the two roots $k_2=p\pm(-3)^{1/2}$. Choosing the $+$ sign and using (7'), $\sum y^3$ is calculated to be equal to $72(-3)^{1/2}(p^2+3)[p+(-3)^{1/2}]$. If we choose the $-$ sign, we obtain $-72(-3)^{1/2}(p^2+3)[p-(-3)^{1/2}]$. The transformed equation is then

$$y^3-24(-3)^{1/2}(p^2+3)[p+(-3)^{1/2}]=0. \tag{14}$$

Hence we state the following

THEOREM III. *Every rational cubic whose Galois group for the field of rational numbers is the cyclic group can be transformed into a binomial cubic of the form* (14), *where the coefficients of the transformation also involve $(-3)^{1/2}$, but no other irrationality.*

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[1] See Florian Cajori, *Theory of Equations*, p. 197.

The general type of the reduced equation, though certainly not its very simple form, could have been foretold from the results at the beginning of section 2.

If we consider the transformed equation in the form (14), and use (12), where y_i is now a root of (14), we can express the roots of the original cyclic cubic (13) as follows:

$$x_i = [p + (-3)^{1/2}]\frac{y_i + 2(-3)^{1/2}p + 6}{y_i + 2(-3)^{1/2}p - 6}.$$

5. Rational Cubics with a Rational Root. It is easily seen that if a cubic of form (1) has a rational root, it must be of the type $x^3+(n-r^2)x-rn=0$, where r is the rational root and n is also rational. In this case we have

THEOREM IV. *Any rational cubic with a rational root can be transformed, by a rational Tschirnhaus transformation, into an equation of the form* $y^3+sy=0$, *where* s *is rational.*

The procedure in this case is somewhat different, for we are now seeking to make $\sum y^3$ equal to zero. If we substitute $a_2=n-r^2$, $a_3=-rn$, in (7), the equation $\sum y^3=0$ becomes

$$3rnk_2^3+2(n-r^2)^2k_2^2-3rn(n-r^2)k_2+3r^2n^2+(2/9)\ (n-r^2)^3=0.$$

It can be easily verified, though less easily derived, that this equation has the rational root $k_2=(r^2+2n)/(-3r)$. We note that if r is zero the given equation already has the required normal form, and no transformation is necessary.

If we substitute this value of k_2 in (6) and take $m=1$, $\sum y^2$ reduces to $(2/9)r^{-2}(2r^2+n)^2(r^2-4n)$, and the transformed equation is $y^3-(1/9)r^{-2}(2r^2+n)^2\ (r^2-4n)y=0$, which is of the desired form.

BENJAMIN PEIRCE'S LINEAR ASSOCIATIVE ALGEBRA AND C. S. PEIRCE

By RAYMOND CLARE ARCHIBALD, Brown University

Since the greater part of an issue of this Monthly (January, 1925) was devoted to the life and work of Benjamin Peirce, it would seem appropriate to place on record in the same publication a vigorous document of his very able son, the late C. S. Peirce. This document, dated June 28, 1910, is a two page sheet which was in his copy of Jordan's *Traité des Substitutions et des Equations Algébriques*. It was written by Peirce in his seventy-first year. Except for the footnotes, which I have added, the transcription of the document is as follows:

"I will record a reminiscence about this book. It was published in 1870, the same year as the date of the original edition of my father's *Linear Associative*

Algebra (though I am sure this was not lithographed for a year or two after the general theory was complete). I had first put my father up to that investigation by persistent hammering upon the desirability of it. There was one feature of this work, however, which I never could approve of, and in vain endeavoured to get him to change. It was his making his coefficients, or scalars, to be susceptible of taking imaginary values. In vain I represented to him that the system of imaginary quantity has two dimensions, and is consequently a double algebra. But it was always next to impossible to induce him to take a logical view of any subject. He did me the honor to reply to my arguments in a footnote on p. 19 of the Ed. of 1870 (p. 9 of that of 1882).[1] The reply is pure bosh. His "broad philosophy" which could not be definitely expressed, was a mere habit of feeling. He was a creature of feeling, and had a superstitious reverence for "the square root of minus one"; and as to the absence of it "trammeling" research, that only means that he was not in possession of any machinery for dealing with the problems that lie beyond its scope. If Hamilton had done as he would have had him, the calculus of quaternions could not have come into being, because division would not generally have had a determinate result. The substance of this work of Jordan was inaccessible to mathematicians who did not choose to devote near a life-time to it, before the work appeared, but if my father had been able to acquaint himself with the Galois theory of equations, and had taken advantage of the possibility, he certainly must have come to see that I had been quite right in my contention. I happened to be in London in 1870 and coming across the book on Hachette's counter purchased it. But I turned it over to the Coast Survey and so was subsequently forced to surrender it along with much else that maimed me intellectually. The dirty fellows who played me this trick got nothing by it except the pleasure of harming me. My activities not lying in the direction of mathematics, I never, while I had the book, got time to master it. When I found that my brother[2] had purchased the book in 1874, I told him it was the very book he needed to study, and that he would get a flood of illumination

[1] C. S. Peirce was the editor, with "addenda and notes," of the second edition of his father's *Linear Associative Algebra*. The footnote here referred to is as follows: "Hamilton's total exclusion of the imaginary of ordinary algebra from the calculus as well as from the interpretation of quaternions will not probably be accepted in the future development of this algebra. It evinces the resources of his genius that he was able to accomplish his investigations under these trammels. But like the restrictions of the ancient geometry, they are inconsistent with the generalizations and broad philosophy of modern science. With the restoration of the ordinary imaginary, quaternions becomes Hamilton's biquaternions. From this point of view, all the algebras of this research would be called bi-algebras. But with the ordinary imaginary is involved a vast power of research, and the distinction of names should correspond; and the algebra which loses it should have its restricted nature indicated by such a name as that of *semi-algebra*."

[2] J. M. Peirce, for forty-five years professor of mathematics at Harvard University.

from it. But he only cut the leaves of the first sheet, and remained to his dying day a superstitious worshipper of two hostile gods, Hamilton and the scalar $\sqrt{(-1)}$. As a professor of mathematics, one would have thought he might have fancied getting some insight to the mathematical advances of his day, most of which have involved the influence of this work; but that wasn't his nature. He was also largely a creature of feeling though his feelings were not of the violent kind. When he died, he left me, as his sole but sufficient legacy (I being the only poor member of the family) his mathematical books, having previously dispossessed himself of every one that he knew I particularly desired. He thought I had a copy of this."

July, 1927.

QUESTIONS AND DISCUSSIONS

EDITED BY H. E. BUCHANAN, Tulane University, New Orleans, La.

The department of Questions and Discussions in the Monthly is open to all forms of activity in collegiate mathematics, including the teaching of mathematics, except for specific problems, especially new problems, which are reserved for the separate department of Problems and Solutions.

DISCUSSIONS

I. A GENERALIZATION OF THE STROPHOID

By F. H. HODGE, Purdue University

We start with a circle of radius $a+k$ tangent to the y-axis at the origin and a fixed point A with coordinates $(a, 0)$. A line through A meets the circle in the points P and P'. We lay off on this line $MP=PN=OP$ and $M'P'=P'N'=OP'$. (See Fig. 1) The locus traced by M, N, M', and N' as the line rotates about A (See Fig. 2) is the curve that we are to consider.

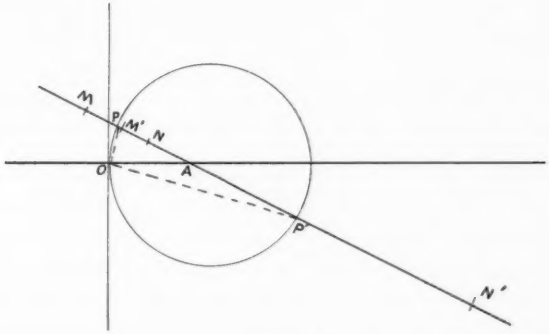

FIG. 1.

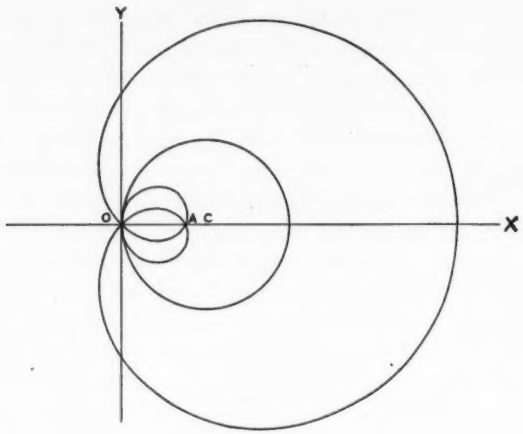

FIG. 2.

To derive its equation we note that the equation of the circle is $x^2-2(a+k)x+y^2=0$ and that the equation of the line is $y=m(x-a)$.

The coordinates of P and P', which we will designate by (ξ, η), must satisfy both of these equations which gives us

$$(1)\qquad \xi = a + \frac{k \pm [(1+m^2)(a^2+2ak)+k^2]^{1/2}}{1+m^2}; \qquad \eta = m\frac{k \pm [(1+m^2)(a^2+2ak)+k^2]^{1/2}}{1+m^2}.$$

If (x, y) represents a point on the curve in question we have, by the conditions of the problem, $(x-\xi)^2+(y-\eta)^2=\xi^2+\eta^2$ or

$$(2)\qquad x^2+y^2-2x\xi-2yn=0.$$

Substituting the values of ξ and η given above we get

$$(3)\quad (1+m^2)(x^2+y^2-2ax)-2(k\pm[(1+m^2)(a+2ak)+k^2]^{1/2})(x+my)=0$$

as the required equation. This equation involves the parameters a and k which are characteristic of the curve and also the quantity m which is connected with x and y by the relation $y=m(x-a)$ and hence may be eliminated.

If now the value of k increases indefinitely the circle approaches the y-axis and this construction becomes the classic construction of the Strophoid as is given, for example, in Woods and Bailey's *Analytic Geometry and Calculus*, page 86. In this case we wish finite values of x and y to be determined by finite

values of m and accordingly we use the negative sign with the radical. For an infinite value of k

$$k - [(1 + m^2)(a^2 + 2ak) + k^2]^{1/2}$$

takes the form $\infty - \infty$.

Evaluating this by the methods of indeterminates, it reduces to $-a(1+m^2)$ which, when substituted in (3), reduces it to the form

$$x^2 + y^2 + 2amy = 0$$

or, since

$$m = \frac{y}{x - a},$$

to the form

$$y^2 = x^2\frac{a - x}{a + x},$$

which is a standard form of the equation of the Strophoid.

Returning to equation (3) we note that, since $m=y/(x-a)$, this equation contains only even powers of y, and the curve is symmetric with respect to the x-axis. If $y=0$, $m=0$ unless $x=a$. We wish to determine the points of the curve, other than $(a, 0)$, where it meets the x-axis. If $y=0$ and $m=0$, the equation becomes

$$x[x-2a-2k\pm 2(a+k)]=0.$$

On account of the double sign we have two equations $x(x-2a-2k-2a-2k)=0$ which gives $x=0$, $4(a+k)$ and $x(x-2a-2k+2a+2k)=0$ which gives $x=0$, 0. Thus the origin is a triple point and the curve also cuts the x-axis at $(0, 4a+4k)$ as is evident from the construction.

Consider now the point $(a, 0)$. For these values the equation becomes

$$a(1 + m^2) + k = \pm 2[(1 + m^2)(a^2 + 2ak) + k^2]^{1/2}$$

or, on rationalizing,

$$(1 + m^2)[a^2(1 + m^2) + 2ak - 4(a^2 + 2ak)] = 0,$$

which gives $m = \pm a^{-1}(3a+2k)^{1/2}$ or $\pm i$. This indicates that the point $(a, 0)$ is an ordinary double point and also an isolated double point.

If we put $m=y/(x-a)$ in the equation of the curve and rationalize, we get an equation of degree eight which, however, contains $(x-a)^2+y^2$ as a factor, indicating that $(a, 0)$ is an isolated double point of the curve.

II. On the Origin and Development of the Idea of "Per Cent"

By Bibhutibhusan Datta, University College of Science, Calcutta

"The origin and development of the idea of per cent, including the question of symbolism," has been put as a topic for discussion by Professor David Eugene Smith in his *History of Mathematics*. In fact the book abounds with many such interesting and valuable topics. As regards the question of symbolism, I know nothing more than what has been given by Professor Smith. I can, however, add to the stock of information relating to the origin and development of the idea.

It has been suggested in the above mentioned book that the idea of per cent probably originated with the early Romans (about the beginning of the christian era) who in fixing taxes in certain cases "made use of fractions which easily reduce to hundredths."[1] But in India instances of the actual use of per cents are found many years earlier. Thus in Kauṭilya's *Arthaśāstra*,[2] a work of the 4th century B. C., it is laid down: "An interest of a paṇa and a quarter per month per cent is just. Five paṇas per month per cent is commercial interest (vyāvahārikī). Ten paṇas per month per cent prevails among forests. Twenty paṇas per month per cent prevails among sea traders (sāmudrānām)." (III. 11, p. 214). In restoring valuable lost articles, such as precious stones, the king was used to demand from the owner a ransom amounting to five per cent of their value. (III. 16, p. 233). In case of gambling, betting, etc., five per cent of the stakes won by every winner was to go to the state. (III. 20, p. 241). Again, "The superintendent of commerce shall fix a profit of five per cent over and above the fixed price of local commodities, and ten per cent on foreign produce." (IV. 2, p. 252). Similar instances of the use of per cent are found in other early works of India, especially in the *Smriti Śāstras*.[3]

Thus it appears as an undoubted fact that the idea of per cent was current in India from the 4th century B. C. There are materials to prove that it must have originated a few centuries earlier. The original Sanskrit terminology for "five per cent," for instance, is *pañcakam śatam*, which literally means "five in the hundred." The expression *pañca śatam* means "five hundreds"; it may also mean "one hundred and five." The first expression differs from the second by the addition of the suffix *ka* to the number name. Similarly, *aṣṭakam śatam* means "eight in the hundred" whereas *aṣṭa śatam* means "eight hundreds" or "one hundred and eight"; and so on. Again, *nava-bhāgikam śatam* (or *nava-bhāgyam śatam*) means "one-ninth in the hundred," whereas *nava-*

[1] David Eugene Smith, *History of Mathematics*, vol. 2, p. 248.

[2] Kauṭilya's *Arthaśāstra*, edited and translated into English, R. Shamasastry, Mysore.

[3] See *Manu Smriti*, Bombay (1915), viii. 139–142, 152. This work in its present form was written in the first century B. C. The original work was composed much earlier. Compare also, *Yājñavalkya Smriti*, ii. 37, 38; *Kātyāyana*.

bhāgam śatam means "one-ninth of the hundred" or "hundred and one-ninth." The celebrated grammarian Pānini (*c.* 700 B.C.) has laid down rules validating the introduction of the suffix *ka* (also *ya* in case of fractions) to the number names in case of "an interest, a rent, a profit, a tax, or a bribe given" to signify "that there in."[1] Now Pānini must have known instances of the use of expressions of this kind in the literature of his age or anterior to his age. Otherwise he would not have framed rules for regulating the formations of the epithets of the aforesaid kind. Hence it follows that the idea of per cent was known in India in the 7th century B.C., or earlier.

It should also be noted that Pānini's sūtras can have probably wider applications; that is, in their applications the base in computation need not necessarily be hundred, it can be any number whatsoever. But in the absence of a specific instance, specially when we remember the highly compact nature of the Sanskrit Sūtra language, it is difficult to give a definite opinion one way or the other. There is, however, one instance in the *Gotama Sūtra*, where it is stated that "an interest of five *māṣās* per twenty per month is just."[2] Apparently the base is twenty. Though it can be easily made hundred, it is not easy to say whether per cent was being recognized as such in those ages.

In China, the idea of per cent is found for the first time in the second section of the *Chiu-chang Suan-shu* or the "Arithmetic in Nine Sections," "which treats of questions in simple percentage and proportion."[3] The use of per cent is found in the *Hsia-hou Yang Suan-ching* or the "Arithmetical Classic of Hsia-hou Yang" (*c.* 550); and in the *Chang Ch'iu-chien Suan-ching* or the "Arithmetical Classic of Chang Ch'iu-chien" (*c.* 575). In 1299, Chu Shih-chich also treated of examples involving percentage partition. Neither the authorship, nor the time of composition of the "Arithmetic in Nine Sections" can be settled definitely, for by an edict of the despotic emperor Shih Hoang-ti, all books were burned and all scholars were buried in 213 B.C. It has been stated in 263 A.D. by the commentator Liu Hui that the work was rewritten by Chang T'sang (died 152 B.C.), on the basis of some old writings. It was subsequently revised and enlarged by Ching Ch'ou-ch'ang (*c.* 60 B.C.). In such circumstances it cannot be safely asserted that the idea of per cent was known in China before the 2nd century B.C. There is nothing relating to it in the oldest mathematical compendium of the Chinese, *Chou-pei*, whose composition is believed to have commenced in the 12th century B.C. and which in course of time was augmented in volume owing to later interpolations by different writers in different ages.

[1] See *Pānini's Grammar*, v. i. 22, 47, 49.

[2] *Gotama Sūtra*, xii. 26.

[3] Yoshio Mikami, *The Development of Mathematics in China and Japan*, Leipzig (1913), p. 11. My information about the Chinese mathematics is derived from this source.

RECENT PUBLICATIONS

EDITED BY W. B. CARVER, Cornell University to whom books and communications should be sent.

NEW BOOKS RECEIVED

BALL, W. R. *Récréations Mathématiques.* Second French edition: third part. Translated by J. Fitz-Patrick. Paris, J. Hermann, 1927. 363 pages.

BURGESS, R. W. *Introduction to the Mathematics of Statistics.* Boston, Houghton Mifflin Company, 1927. ix+304 pages. $2.50.

CARMICHAEL, R. D. and WEAVER, J. H. *The Calculus.* Boston, Ginn and Company, 1927. xiv+345 pages.

COURNOT, AUGUSTIN. *The Mathematical Principles of the Theory of Wealth.* Translated by N. T. Bacon, with notes and a bibliography by Irving Fisher. New York, The Macmillan Company, 1927. xxiv+209 pages.

DESCARTES, RENÉ. *La Géométrie.* Nouvelle edition. Paris, J. Hermann, 1927. 91 pages.

LAMÉ, G. *Exposé des Méthodes pour Résoudre les Problèmes de Géométrie.* Paris, J. Hermann, 1927. xii+124 pages.

POTRON, ABBÉ. *Exercises de Calcul Différentiel et Intégral.* Second volume, Solutions of the exercises. Paris, J. Hermann, 1927. iii+258 pages.

REVIEWS

Modern Algebraic Theories. By L. E. DICKSON. Chicago, Benjamin H. Sanborn, 1926. ix+276 pages. Price $3.50.

The modern algebra of 1800 was "a thing of shreds and patches." The fundamental theorem of algebra had but lately been proved and certainly was not generally understood. The theory of equations was to a large extent a formal or symbolic matter, for what could Newton's formulae or Cardan's solution mean to a man who had neither Argand's diagram nor Sir William Hamilton's fundamental method of creating complex numbers? The theory of groups was in its infancy, the word invariant was unknown and the phenomenon of invariancy had been observed in only a few special cases, even the possibilities of determinants were unexplored.

Then began the golden age of algebra; Lagrange was its precursor; pregnant words—transformation, group invariant, matrix, hypercomplex, rank—shining names—Gauss, Abel, Galois, Cayley, Jacobi, Hermite, Kronecker, Klein, Frobenius . . . . connote its developments. Whence came this new algebra, the modern algebra of to-day? It has its roots deep in the past, in the questions the Greeks and possibly the Egyptians asked about the regular solids, in the age-old speculations on the nature and meaning of number, in the Arabic solution of the quadratic, and in the terrific struggles of the Italians of the Renaissance with the cubic and the biquadratic. For centuries profound

questions had been accumulating. With what maddening slowness were they solved! It required three centuries—from Fibonacci to Cardan—for the cubic, two long centuries from Cardan's use of "sophistic" numbers to any satisfactory theory of imaginary numbers. Then impatient of all this delay came young giants, Gauss, Abel, Galois, Jacobi; as if in feverish haste they solved old problems, threw out new ideas, began to build a science on the foundations that had been laid by rule of thumb. It is an old story, but one which will bear many repetitions, and we need to have it in mind for the full appreciation of this remarkable book in which a great algebraist presents the essentials of algebra as it is to-day.

The first two chapters of "Modern Algebraic Theories" give an introduction to the non-symbolic theory of algebraic invariants and covariants of binary forms. A treatment of the theory of invariants of forms in more than two variables and the special theory of binary forms of higher order would require an apparatus of multiple subscripts and of symbols too difficult and too technical for students at the begining of their graduate work, and if undertaken, might obscure the important idea of invariance. Professor Dickson in these two chapters, with a total of only thirty-eight pages, avoids the lure of subscripts and symbols, and passes swiftly and simply from the definition of invariants and covariants up to his goal, the proof, through the use of Hilbert's theorem, on sets of forms in n variables, of the finiteness of a fundamental system of covariants, of a set of binary forms, and the finiteness of the syzygies among the covariants of a given set of binary forms.

In the first of these two chapters, fundamental systems of covariants of the binary forms of order less than five are found, the cubic and quartic are reduced to their canonical forms and these canonical forms are used to find the solutions of the general cubic and quartic equations. The second chapter develops the machinery of annihilators, commutators, and seminvariants necessary for the proof of the finiteness theorem by Hilbert's method, gives the proof, and concludes with an article on Sylvester's reduction of every sufficiently general binary form of order $2n-1$ to a sum of $(2n-1)$th powers of linear forms. To cover so briefly so much of the theory of invariants in a manner which is elementary, attractive, and rigorous, and at the same time to give a deep insight into this theory is an amazing accomplishment.

In the next three chapters we find a novel treatment of matrices, linear forms and linear equations, and of bilinear, quadratic, Hermitian symmetric and Hermitian bilinear forms. This is the part of the book to which the young physicist who wishes to prepare himself to read the new atomic theory will first turn, and he will be glad that these chapters are independent of the first two. The most striking features of this part of the book are the care with which questions of rationality are treated, the elegant solution of the problems

of linear equations, and the unification of the treatment of quadratic, Hermitian symmetric and Hermitian bilinear forms, which makes possible a discussion of these four types of forms in a small space and with little more effort than quadratic forms alone require. Although Hermite introduced into mathematical literature more than seventy years ago the forms which bear his name and showed their utility in his algebraic proof of Sturm's theorem, and although these forms have increased steadily in prominence, there was not, so far as the reviewer recalls, any introduction to them in a text-book in the English language, prior to the publication of the present work. The discussion of the equivalence of pairs of bilinear quadratic and Hermitian forms brings us to the theory of elementary divisors and invariant factors, which are introduced in a natural way through the use of a rational canonical form of a linear substitution.

The second half of the book is devoted to interesting questions to which group theory gives complete and simple answers. In chapters VII–XI the difficult Galois theory of equations is exposed with especial care, and the leisurely and orderly manner in which it is developed makes possible to students at an early stage in their mathematical training a real understanding of the proof that the general equations of the fifth and higher degrees are not solvable by radicals. The proof of this theorem, from the historical point of view the outstanding result of these chapters, is derived from Galois's necessary and sufficient condition for solvability by radicals. It is this part of the work which will really test a student's mettle; if his point of view is only a formal one he may think he understands the first half of the book, but he will have no illusions about the Galois theory.

Questions of construction have had an extreme fascination for many who did not completely understand the nature of the problems they were attempting to solve, and it was a happy thought to include here a short chapter in which the group theory developed in earlier chapters is used to prove that the trisection of an angle with ruler and compass is not always possible, and to settle the whole question of the construction of a regular polygon of n sides. The first question is disposed of by a short and lucid proof that it is not possible with ruler and compasses to trisect the angle 120°, and the second is answered by the explicit theorem that the construction is possible if and only if $n = 2^l p_1 p_2 \cdots$, where the p's are of the form $2^\mu + 1$, where $\mu = 2^k$.

The problem of the quintic was one of the most famous and most intractable legacies of the eighteenth century to the nineteenth; its solution is one of the great mathematical victories of the last century. This significant chapter in the history of mathematics—in so far as it falls in the domain of algebra—is imbedded in the latter half of the book. First, we have the proof of the

capital result mentioned above that the general quintic is not solvable by radicals, in Chapter XII the tale is taken up again and we find Bring's method of reducing the quintic to the form $y^5+dy+e=0$, a result published in 1786. This form has great historical interest on account of its being the one used by Hermite in his first solution of the quintic (by elliptic functions) in 1858, but it is a less remarkable result than Brioschi's, for not only does Brioschi's form involve a single parameter, but the reduction to this form involves only square roots, whereas the reduction to Bring's form introduces a cube root as well. The connection of the quintic with the icosahedron and the proof that the general quintic can be solved in terms of two square roots and a root of the icosahedral equation holds a central position in Chapter XIII, where we find a readable account of the groups of the regular solids and their applications to the theory of equations as set forth in Klein's *Icosahedron*. In a day when the extent of mathematics is too vast for all except encyclopedic minds, Klein's classic work has few readers, and many more mature readers than those for whom *Modern Algebraic Theories* is especially written will be glad of the opportunity to get the gist of the *Icosahedon* from Dickson's short and interesting resume.

The final chapter treats of the representations of a finite group as a linear group and gives an account of Schur's exposition of the theory of group characters, a powerful tool in the solution of problems in the theory of finite groups.

Any text-book from Professor Dickson's pen is a combination of sound and brilliant scholarship. The present work is particularly useful in taking almost all of modern algebra for its field and presenting this with rare skill. Though the author is master of every weapon of the algebraic art, he uses his art not to mystify the reader or to display his own learning, but to make the obscure clear and to reveal the essence of algebra as it is at the end of the first quarter of the twentieth century. Details such as titles to each of the articles, theorems printed in italics and stated in a form which makes the book valuable for reference, list of topics for further reading, carefully chosen lists of problems, references to original sources, all these add to the value of a work which will be a standard text-book for generations of graduate students and will furnish a useful outline of modern algebra for many mathematicians and physicists whose special interest lies in other fields than algebra. Like any book of permanent value, this will bear reading again and again. To the student who reads and rereads, ponders deeply and inwardly digests, it will reveal not only the vast science and art of algebra as it is to-day, but will give more than an inkling of the algebra of to-morrow.

W. L. G. WILLIAMS.

Mathematics for Engineers. By R. W. DULL. New York, McGraw-Hill Book Company, 1926. xvii+780 pages.

This recapitulation of the mathematics employed in ordinary engineering practice is an expansion of a set of notes compiled by the author for his own convenience, and is intended to be a reference book for engineers. The subjects treated are: numerical computations; algebra, beginning with the rudiments and including cubic equations, logarithms and exponentials, series, determinants, and combinations and permutations; trigonometry, vectors, and hyperbolic functions; plane and solid analytic geometry; calculus, including nine pages on the differentiation of functions of more than one variable. Differential equations are not considered. Much of the material should be familiar to alumni of our engineering schools. Yet some of them may find it convenient to have a book in which they can look up methods which, through disuse, have become unfamiliar. The book is planned to facilitate the acquirement of mathematical technique. It is no text for the student of mathematics as such.

The subject matter is conveniently arranged for reference in fifty-seven chapters and over a thousand numbered articles. The explanations are in simple form, and are illustrated by practical applications. A cursory examination of the 767 pages of text revealed no serious flaws. The illustrative figures are good. But many of them are much too small. Fig. 574 of page 659 is an example.

J. E. TREVOR

ARTICLES IN CURRENT PERIODICALS

The lists appearing regularly in the Monthly of articles in current periodicals are intended to include (1) titles of papers in all mathematical journals published in the United States; (2) titles of mathematical papers and reports published by the national and state academies of science and in journals devoted to general science; (3) titles of mathematical papers by American authors published in foreign journals.

American Journal of Mathematics, volume 50, no. 3, July 1927: "Linear ordinary self-adjoint differential equations of the second order," by Anna Pell Wheeler, 309–320; "The singularities of a function defined by a Dirichlet series," by D. V. Widder, 321–328; "On entire function interpolation," by I. M. Sheffer, 329–342; "Optics in space of constant non-vanishing curvature," by James Pierpont, 343–354; "On an imprimitive group of order 5184," by J. R. Musselman, 355–366; "Rational involutorial transformations in S_4 which leave invariant ∞^4 quadric surfaces," by H. C. Shaub, 367–382; "A three-dimensional quartic variety in four-space," by B. C. Wong, 383–388; "Compound singularities of the rational plane quartic curve," by J. H. Neelley, 389–400; "Pencils of conics in the Galois field of order 2^n," by A. D. Campbell, 401–406; "On generalized Lacunae," by J. J. Gergen, 407–418; "Properties of certain aggregate functions," by L. S. Hill, 419–432; "The theory of group-reduced distributions," by J. H. Redfield, 433–455; "Closure of the tangential process on the rational plane cubic," by F. E. Allen, 456–461.

Bulletin of the American Mathematical Society, volume 33, no. 5, September-October 1927: "On the geometry of linear displacement," by D. J. Strink, 523–564; "Concerning the boundaries of domains of a continuous curve," by W. L. Ayres, 565–570; "A theorem on connected point sets," by C. Kuratow-

ski and C. Zarankiewicz, 571–575; "On certain sufficient conditions for the convergence and Cesâro summability of the allied series of a double Fourier series," by G. M. Merriman, 576–582; "A general theorem on quantic determinants," by T. R. Rosebrugh, 583–590; "On the degree of approximation to a harmonic function," by J. L. Walsh, 591–598; "On inductive relations," by C. H. Langford, 599–607; "Three-parameter and four-parameter linear families of conics in the Galois field of order 2^n," by A. D. Campbell, 608–612.

Messenger of Mathematics, volume 57, no. 1, May 1927: "Some remarks on the wave-theory of matter," by Dr. H. Bateman, 7–11.

The Quarterly Journal of Mathematics, volume 50, no. 4, September 1927: "Periodic functions of n variables connected with an algebraic number field of degree n," by E. T. Bell; "The generalized Hessian," by T. R. Hollcroft, 362–372.

PROBLEMS AND SOLUTIONS

EDITED BY B. F. FINKEL, OTTO DUNKEL, AND H. L. OLSON

Send all communications about Problems and Solutions to B. F. Finkel, Springfield, Mo. All manuscripts should be typewritten, with double spacing and with a margin at least one inch wide on the left.

PROBLEMS FOR SOLUTION

N.B. Problems containing results believed to be new, or extensions of old results are especially sought. The editorial work would be greatly facilitated if, on sending in problems, proposers would also enclose any solutions or information that will assist the editors in checking the statements. In general problems in well-known textbooks, or results found in readily accessible sources, will not be proposed as problems for solution in the Monthly. In so far as possible, however, the editors will be glad to assist members of the Association with their difficulties in the solution of such problems.

3295. Proposed by Nathan Altshiller-Court, University of Oklahoma.

Given a complete quadrilateral it is possible to describe three circles having their centers at the vertices of the diagonal triangle so that the vertices of the quadrilateral shall be the center of similitude of the three circles taken in pairs. Moreover one of the three radii may be taken arbitrarily.

NOTE. This is the converse of the known proposition: The centers of similitude of three given circles taken in pairs are the vertices of a complete quadrilateral. See, for instance, Nathan Altshiller-Court, *College Geometry*, p. 160, Johnson Pub. Co., Richmond, Va., 1925.

3296. Proposed by J. Rosenbaum, Milford, Connecticut.

It is well known that the radius of the inscribed circle of a right triangle is equal to half the difference between the sum of the legs and the hypotenuse. Derive an analogous expression for the radius of the inscribed sphere of a right tetrahedron.

3297. Proposed by C. N. Mills, Normal, Illinois.

Suppose BOD to be a quadrant of a circle of radius R; find the radius of a circle inscribed therein. Also find the radius of a circle which will touch both circles and the line OB.

3298. Proposed by W. A. Thompson, Supt. of Schools, Webster, South Dakota.

Given two circles of unequal sizes, such circles intersecting each other, to draw a secant cutting both circles, such that the chords of the circles are equal to each other and equal to the segment of the line between the two chords.

3299. Proposed by H. W. Reddick, Cooper Institute of Technology, New York, N. Y.

Solve the differential equation

$$\frac{d^{n+1}y}{dx^{n+1}} - \frac{dy}{dx} - \frac{ny}{x} = 0,$$

a generalization of Problem 3227.

3300. Proposed by Emma M. Gibson, High School, Springfield, Missouri.

If u and v are particular integrals of the equation

$$\frac{d^3y}{dx^3} + P\frac{d^2y}{dx^2} + Q\frac{dy}{dx} + Ry = 0,$$

prove that $y=Au+Bv$ is the complete solution, where

$$A'/v=-B'/u=ce^{\mu}/(u'v-uv')^2 \quad (\mu=-\int Pdx),$$

c being a constant and the accents denoting differentiation with respect to x. (University of Edinburgh Examinations, 1903).

3301. Proposed by J. B. Reynolds, Lehigh University.

From the corners of a square sheet of tin are cut out quadrilaterals so that when the sides are turned up the pan formed will have a maximum volume. Find the top and bottom dimensions of the pan.

SOLUTIONS

Algebra 494 [1917, 466]. Proposed by N. P. Pandya, Sojitra, India.

Solve algebraically and also graphically, $\log \sin x = \sin \log x$.

Solution by Otto Dunkel, Washington University.

The logarithmic base will be taken as e. Setting $x=e^t$, $e^{\sin t}=f(t)$, $\sin e^t=\phi(t)$, the equation becomes $f(t)=\phi(t)$. In the interval from $2n\pi$ to $(2n+1)\pi$, $n=$ an integer, $f(t)$ increases from unity to e and then decreases to unity; in the interval from $(2n-1)\pi$ to $2n\pi$, $f(t)$ decreases from unity to $1/e$ and then increases to unity. In each interval the curve for $f(t)$ is symmetrical about the vertical at the mid-point of the interval. Since $\phi(t)$ is never more than unity, roots can occur only in the interval $(2n-1)\pi \leqq t \leqq 2n\pi$.

It will be shown that there are no negative roots. Set $t'=-t>0$. Then $\sin t'<t'$, $e^{\sin t'}<e^{t'}$, $e^{-t'}<e^{-\sin t'}$, and finally $\sin e^{-t'}<e^{-t'}<e^{\sin(-t')}$, or $\phi(t)<f(t)$. It remains to examine the intervals $(2n-1)\pi \leqq t \leqq 2n\pi$, for $n=1, 2, 3, \cdots$. As t passes from one end of the nth interval to the other, the number of periods of $\sin x=\phi(t)$ is the integral part of $e^{(2n-1)\pi}(e^{\pi}-1)/2\pi$; and the number of roots in the interval is at least twice this integer. The number of roots in the interval increases very rapidly with n. A pair of roots are separated by $k=\log_e[(4m+1)\pi/2]$, where m is a positive integer chosen so that k falls within the interval for t.

The first interval which contains roots, $\pi \leqq t \leqq 2\pi$, will be considered. Here $e^{\pi}=23.14061=7.36591\pi$, $e^{\pi}(e^{\pi}-1)=163.0851\pi$. There are then at least 162 roots in this interval. An examination of the ends of the interval shows that there are precisely 162 roots. To separate the first two roots, we take $m=4$, and then $k=\log_e(17\pi/2)=3.2848$. Since the two roots separated differ very little, this number suggests a first approximation to either root. The usual processes of approximation give the results: first root, $t=3.26633$, $x=26.2150$; second root, $t=3.30539$, $x=27.2593$. The third and fourth roots are separated by 3.4961. The second interval contains about 87,330 roots.

3212. [1926, 429]. Proposed by A. A. Bennett, Lehigh University.

The following scheme portrays an example in ordinary "exact" long division. The symbol x, merely indicates the presence of a digit. The divisor appears upon the left and the quotient on the right. A letter, such as a, b, c, etc., denotes a digit and when one of the letters, (not x) is used in two places, this signifies that the same digit is to be used in both places. However, distinct letters do not necessarily denote distinct digits.

Find the divisor and quotient and prove that your solution is the only one possible.

$$
\begin{array}{l}
x\,x\,x\,x\,x\,a\,b\,x\,x\,x\,x\;)\;x\,x\,x\,x\,x\,x\,x\,x\,x\,x\,x\,x\,x\,x\,x\,c\,c\,f\,x\;(\;x\,c\,x\,x\,x\,x\,x\,x \\
\qquad\qquad\qquad

of r different from g, merely rotating the cycle. In the case of equal digits, a different r will also yield equal digits, and we have already excluded this case. For $q_5=7$, except for $2r+g$ divisible by 7, all remainders but one occur on obtaining each cycle. This one occurs when $2r+g$ is divisible by 7, and yields a succession of equal digits, requiring $a=b$, already excluded. Hence, excepting this value for r, the cycle will rotate also for the other values. For $g=0$, the successive digits of D are equal, except when $q_5=7$ and $r\neq 7$, yielding only the cycle 142857, already included in the table. The remaining case for $q_5=7$, where $g=7$ and $r\neq 7$, yields the additional sequence 253968.

With this one exception, the numbers in this table represent then all possible sequences of digits in D. Moreover, it is clear that any multiple of D, such as q_3D, will yield a sequence of digits found in the *same column* with that of D barring a possible succession of equal digits. The latter is barred out for q_3D, since $a\neq b$. Since $a+d=0$ or 10, and no two adjacent digits are 0, $a+d=10$ and $ad\neq 0$. We have then to locate those pairs of adjacent digits (representing da in q_3D) totalling 10. For $q_5=3$ or $q_5=6$, the only possibility is $d=3$, $a=7$. But the digit preceding d, namely b, would then be 0. Hence $q_5\neq 3$ or 6. The remaining possibilities are included in the table below.

Here, for example, 73 occurs in the first sequence of the column headed $q_5=7$ in the previous table. The digit before d, 8, in the cycle must represent b, and the next but one after a, 1, must represent e, etc. The last set for $q_5=7$ is found in the exceptional sequence 253968. But we must have $b+e=10$. This excludes $q_5=9$, whence $q_5=7$. The only possibilities are then $d=4$ or 1. The former requires $a=6$, $b=7$. The pair 67 would then occur in D. But no such pair occurs among the permissible sequences under $q_5=7$. Hence $d\neq 4$. Hence the only possibility is $d=1$, $a=9$, $b=6$, $e=4$. Using the multiplier $q_5=7$ on the pair 96 in D, we obtain $g=7$. Since $d=1$, $t_{11}=3$. Proceeding from right to left, we find the remaining digits of D, giving $D=68253968253$, requiring $r=4$. Obviously, $q_1=1$, $q_4=8$, and $q_6=7$. Also q_3 must be 3. Further, the remainder previous to the last ends in $89x$. The product beneath ends in 771. Hence the 9th digit in the final remainder must be 1. For this the only possibility is $q_7=5$. The division is then automatically completed. The quotient is 1038775, and the dividend is readily found to be 70900515872010075.

$q_5=7$	$q_5=9$
$d\ a\ b\ e$	$d\ a\ b\ e$
7 3 8 1	4 6 2 1
4 6 7 3	9 1 6 5
1 9 6 4	3 7 0 3
2 8 4 7	8 2 3 1
8 2 6 3	2 8 7 9
	6 4 8 9
	1 9 4 5

Also solved by H. C. BRADLEY, J. M. BARBOUR, and F. L. WILMER.

3222. [1926, 481]. Proposed by Norman Anning, University of Michigan.

Under what conditions is it possible to choose five points in space such that the straight line joining any two shall be perpendicular to the plane which contains the remaining three?

SOLUTION BY OTTO DUNKEL, Washington University.

Suppose that the five distinct points A, B, C, D, E, satisfy the conditions of the problem; then no three lie in a straight line and no four lie in a plane. The conditions of the problem will be satisfied if $AE\perp BCD$, $BE\perp CDA$, $CE\perp DAB$, $DE\perp ABC$; for any other straight line, say AB, must then be such that $AB\perp CE$, $AB\perp DE$, and therefore $AB\perp CDE$. Hence if we consider any one of the five tetrahedrons, say $ABCD$, its altitudes must meet in the remaining point, E. Since $AB\perp CDE$, the plan CDE cuts the face ABC in an altitude of the triangle. Hence DE cuts ABC in its orthocenter. Similar results follow for the remaining altitudes of the tetrahedron.

Conversely, to select the five points, we take any three points A, B, C which form a triangle, and at its orthocenter D' we construct the perpendicular to its plane. For D we take any point, other than D', on this perpendicular. Then $DD'\perp ABC$ and thus $DD'\perp AB$. Also by construction $CD'\perp AB$. It now follows that $AB\perp CDD'$ and then that $AB\perp CD$. Similarly, we show that $AC\perp BD$. Since $AB\perp CDD'$, $ABD\perp CDD'$. Hence a perpendicular from C to ABD must lie in CDD' and it cuts DD' in a point which we take for E. It will be shown that A, B, C, D, E, selected in this way, satisfy the sufficient conditions stated above. Since $CE\perp ABD$, $CE\perp BD$; and it was shown above that $AC\perp BD$.

Hence $BD \perp ACE$. Let CE cut the face ABD in C'. Hence the plane ACC' cuts the face ABD in an altitude AC'. Since $AB \perp CDD'$, DC' is also an altitude of the face ABD, and therefore C' is the orthocenter of ABD. Reasoning as above, using first DD' and then CC', we see that the perpendicular from B to ADC must cut each of these lines; hence it passes through their intersection E. Similarly, the perpendicular from A to BCD passes through E, and this completes the proof. See 3187 [3175; 1926, 228].

Also solved by THEODORE BENNETT, W. L. AYRES, NATHAN ALTSHILLER-COURT, MICHAEL GOLDBERG, J. ROSENBAUM, and ROSCOE WOODS.

3226 [1926, 524]. Proposed by H. E. Trefethen, Colby College.

The cross section of a circular ring is crescent shaped. The outer arc is a semicircle. The inner arc has a radius of one inch and its center is at the center of the ring. Find the greatest possible volume for the ring.

SOLUTION BY OTTO DUNKEL, Washington University

The inner and outer arcs of the generating crescent have the equations $y_i^2 = 1 - x^2$ and $y_0 = (1-c^2)^{1/2} + (c^2 - x^2)^{1/2}$, where $2c$ is the length of the common chord. Hence $y_0^2 - y_i^2 = 2(1-c^2)^{1/2}(c^2-x^2)^{1/2}$. If we multiply this by $2\pi dx$ and integrate from 0 to c, we shall obtain the volume V. The result is obviously $\pi(1-c^2)^{1/2}$ times the area of a circle of radius c. Hence $V = \pi^2 c^2 (1-c^2)^{1/2}$. If $c = (2/3)^{1/2}$ we have the maximum value of V, namely, $2\pi^2 \cdot 3^{-3/2}$.

Also solved by H. S. UHLER, V. W. ADKISSON, R. P. AGNEW, T. ANDREW, W. L. AYRES, M. GOLDBERG, D. F. GUNDER, W. F. HUBERT, ELMER LATSHAW, W. K. NELSON, A. PELLETIER, G. E. RAYNOR, C. H. VEHSE, and F. L. WILMER.

3227 [1926, 524]. Proposed by H. W. Reddick, Cooper Union Institute of Technology.

Solve the differential equation

$$\frac{d^3y}{dx^3} - \frac{dy}{dx} - \frac{4y}{x} = 0.$$

SOLUTION BY FREDERIC H. MILLER, Cornell University

Employing the operator D to denote differentiation with respect to x, we may write the equation in the form

$$(D^3 - D - 4x^{-1})y = 0. \tag{1}$$

Assume a solution of the form $y = x^n e^{ax}$, the values of n and a to be determined by substitution in the differential equation. We then get, after dividing through by $x^{n-3}e^{ax}$,

$$a^3x^3 + 5a^4nx^4 + 10a^3n(n-1)x^3 + 10a^2n(n-1)(n-2)x^2 + 5an(n-1)(n-2)(n-3)x + n(n-1)(n-2)(n-3)(n-4) - ax^3 - nx^4 - 4x^4 = 0.$$

Equating the coefficients of the various powers of x to zero, we find that the only permissible values of n and a are $n = 1$; $a = \pm 1, \pm i$. We therefore have the following known integrals belonging to the complementary function:

$$y = xe^x;\ y = xe^{-x};\ y = x \sin x;\ y = x \cos x.$$

Now introduce a new variable z by setting $y = xe^{-x} \cdot z$; upon substitution in (1) and reducing, we get

$$[xD^3 - 5(x-1)D^2 + 10(x-2)D^2 - 10(x-3)D^2 + 4(x-5)D]z = 0, \tag{2}$$

an equation of the fourth order. When $y = xe^x$,

$$z = y/xe^{-x} = e^{2x}; \quad Dz = 2e^{2x}.$$

Hence we may put $Dz = e^{2x} \cdot w$, where w is a second new variable. This, when substituted in (2), yields

$$[xD^4 + (3x + 5)D^3 + 2(2x + 5)D^2 + 2(x + 5)D]w = 0. \tag{3}$$

For $y = x \cos x$, there is found in a similar manner $Dw = -2e^{-x}\cos x$; so that we may put $Dw = e^{-x}(\cos x)v$. Substituting in (3), we obtain

$$[x(\cos x)D^3 - (3x \sin x - 5 \cos x)D^2 - 2(x \cos x + 5 \sin x)D]v = 0. \tag{4}$$

Taking $y = x \sin x$, we find $Dv = -2 \sec^2 x$. Thus we may set $Dv = (\sec^2 x)u$; equation (4) then becomes

$$[xD^2 + (x \tan x + 5)D]u = 0.$$

the solution of which is

$$u = A \int x^{-5} \cdot \cos x \cdot dx + B.$$

Hence, retracing the above steps, we get finally

$$y = K_1 x e^{-x} \int [e^{2x} \int \{e^{-x} \cos x \int [\sec^2 x \int x^{-5} \cdot \cos x \cdot dx)dx\} dx]dx$$

$$+ K_2 x \sin x + K_3 x \cos x + K_4 x e^x + K_1 x e^{-x}.$$

Also solved by G. E. RAYNOR, J. B. REYNOLDS, J. D. TAMARKIN, and the PROPOSER.

NOTES AND NEWS

Readers are invited to contribute to the general interest of this department by sending items to H. W. Kuhn, Ohio State University, Columbus, Ohio.

SPECIAL NOTE BY THE EDITOR-IN-CHIEF

During the year 1927, thirty six books were reviewed in this Monthly. From the authors of two of them, the editor received letters in reply to criticisms made by the reviewers. One of these letters was published in April (p. 204). The other was not published in this Monthly, but it was distributed recently by the publisher of the book as a circular letter addressed to members of the Association, with the unqualified statement that the editor refused to publish it. The fact of the matter is that the editor, in a note written to the author on May 16, offered to publish the letter if the writer of it would shorten it and eliminate a few objectionable phrases. No reply to that offer was ever received by the editor.

W. H. BUSSEY

Dr. ETHEL L. ANDERTON has been promoted to an assistant professorship of mathematics at Smith College.

Dr. TOBIAS DANTZIG, professor of mathematics at the University of Maryland, will conduct a course in advanced mathematics for physicists and chemists at the Bureau of Standards during the year 1927–28.

Professor H. C. GOSSARD of the University of Wyoming has been appointed professor of mathematics and dean of men at Nebraska Wesleyan University.

Professor CHARLES O. GUNTHER, head of the department of mathematics at Stevens Institute of Technology, has been appointed dean of sophomores to succeed Dr. Sevenoak.

Professor F. R. MOULTON, director of the department of astronomy at the University of Chicago, has resigned, to become associated in an executive capacity with the Utilities Power and Light Corporation of Chicago.

Dr. B. C. PATTERSON has been appointed associate professor of mathematics at Hamilton College.

Associate Professor J. B. REYNOLDS of Lehigh University has been promoted to a full professorship of mathematics and theoretical mechanics.

Miss GEORGIA E. ROBINSON has been appointed professor of physics at Ozark Wesleyan College.

The following appointments to instructorships in mathematics are announced:

Amherst College, Mr. B. LEF. BROWN;
Tulane University, Mr. J. F. THOMSON.

The following have been appointed National Research Fellows in mathematics for 1927–28: W. L. AYRES, R. W. BARNARD, ALONZO CHURCH, C. M. CRAMLET, JESSE DOUGLAS, D. A. FLANDERS, ORRIN FRINK, G. M. MERRIMAN, T. W. MOORE, HILLEL PORITSKY, H. P. ROBERTSON, C. F. ROOS, I. M. SHEFFER, M. M. SLOTNICK, W. M. WHYBURN. (This list includes reappointments).

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Cash will be paid for certain single numbers as follows, up to a limited number of copies:

February, March, May, or September, 1913; September, 1914; February, March, April, or June, 1915; February or September, 1918; fifty cents; September, 1915—seventy-five cents; May, 1915—one dollar (See MONTHLY, March, 1921, p. 152). October, 1920; August, September, or October, 1921; May-September, or October, 1924; May or June-July, or November, 1926—forty-five cents.

Address all communications to the Secretary, W. D. Cairns, Oberlin, Ohio

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INDIANA

INDIANA UNIVERSITY, Bloomington, Ind.
BUTLER UNIVERSITY, Indianapolis, Ind.
PURDUE UNIVERSITY, LaFayette, Ind.
UNIVERSITY OF NOTRE DAME, Notre Dame, Ind.
ST. MARY-OF-THE-WOODS COLLEGE, St. Mary-of-the-Woods, Ind.

IOWA

IOWA STATE COLLEGE, Ames, Ia.
ST. AMBROSE COLLEGE, Davenport, Ia.
DRAKE UNIVERSITY, Des Moines, Ia.
COLUMBIA COLLEGE, Dubuque, Ia.
STATE UNIVERSITY OF IOWA, Iowa City, Ia.

KANSAS

ST. BENEDICT'S COLLEGE, Atchison, Kans.
UNIVERSITY OF KANSAS, Lawrence, Kans.
STATE AGRICULTURAL COLLEGE, Manhattan, Kans.

LOUISIANA

LOUISIANA STATE NORMAL COLLEGE, Natchitoches, La.
LOYOLA UNIVERSITY, New Orleans, La.
TULANE UNIVERSITY OF LOUISIANA, New Orleans, La.
LOUISIANA POLYTECHNIC INSTITUTE, Ruston, La.

INSTITUTIONAL MEMBERS (*continued*).

MASSACHUSETTS

AMHERST COLLEGE, Amherst, Mass.
BOSTON UNIVERSITY, Boston, Mass.
NORTHEASTERN UNIVERSITY, Boston, Mass.
HARVARD COLLEGE, Cambridge, Mass.
WELLESLEY COLLEGE, Wellesley, Mass.
WORCESTER POLYTECHNIC INSTITUTE, Worcester, Mass.

MICHIGAN

ALBION COLLEGE, Albion, Mich.
UNIVERSITY OF MICHIGAN, Ann Arbor, Mich.
COLLEGE OF THE CITY OF DETROIT, Detroit, Mich.
MICHIGAN STATE COLLEGE, East Lansing, Mich.
KALAMAZOO COLLEGE, Kalamazoo, Mich.
MICHIGAN STATE NORMAL COLLEGE, Ypsilanti, Mich.

MINNESOTA

CARLETON COLLEGE, Northfield, Minn.
UNIVERSITY OF MINNESOTA, Minneapolis, Minn.
ST. BENEDICT'S COLLEGE, St. Joseph, Minn.
COLLEGE OF ST. TERESA, Winona, Minn.

MISSOURI

CULVER-STOCKTON COLLEGE, Canton, Mo.
UNIVERSITY OF MISSOURI, Columbia, Mo.
NORTHWEST MISSOURI STATE TEACHERS COLLEGE, Maryville, Mo.
MISSOURI SCHOOL OF MINES AND METALLURGY, Rolla, Mo.
THE PRINCIPIA, St. Louis, Mo.
WASHINGTON UNIVERSITY, St. Louis, Mo.

MONTANA

UNIVERSITY OF MONTANA, Missoula, Mont.

NEBRASKA

UNIVERSITY OF NEBRASKA, Lincoln, Nebr.
CREIGHTON UNIVERSITY, Omaha, Nebr.

NEW HAMPSHIRE

UNIVERSITY OF NEW HAMPSHIRE, Durham, N. H.
DARTMOUTH COLLEGE, Hanover, N. H.

NEW JERSEY

THE NEW JERSEY COLLEGE FOR WOMEN, New Brunswick, N. J.
RUTGERS UNIVERSITY, New Brunswick, N. J.
PRINCETON UNIVERSITY, Princeton, N. J.

NEW MEXICO

NEW MEXICO NORMAL UNIVERSITY, Las Vegas, N. M.

NEW YORK

NEW YORK STATE COLLEGE FOR TEACHERS, Albany, N. Y.
WELLS COLLEGE, Aurora, N. Y.
ADELPHI COLLEGE, Brooklyn, N. Y.
UNIVERSITY OF BUFFALO, Buffalo, N. Y.
HAMILTON COLLEGE, Clinton, N. Y.
ELMIRA COLLEGE, Elmira, N. Y.
COLLEGE OF MOUNT ST. VINCENT, Mount St. Vincent-on-Hudson, N. Y.
COLLEGE OF THE CITY OF NEW YORK, New York, N. Y.
COLLEGE OF THE SACRED HEART, New York, N. Y.
COLUMBIA UNIVERSITY, New York, N. Y.
THE COOPER UNION, New York, N. Y.
HUNTER COLLEGE OF THE CITY OF NEW YORK, New York, N. Y.
NEW YORK UNIVERSITY, New York, N. Y.
UNIVERSITY OF ROCHESTER, Rochester, N. Y.
UNION COLLEGE, Schenectady, N. Y.
UNITED STATES MILITARY ACADEMY, West Point, N. Y.

INSTITUTIONAL MEMBERS (*continued*)

OHIO

UNIVERSITY OF AKRON, Akron, Ohio.
UNIVERSITY OF CINCINNATI, Cincinnati, Ohio.
CASE SCHOOL OF APPLIED SCIENCE, Cleveland, Ohio.
WESTERN RESERVE UNIVERSITY, Cleveland, Ohio.
OHIO WESLEYAN UNIVERSITY, Delaware, Ohio.
KENYON COLLEGE, Gambier, Ohio.
DENISON UNIVERSITY, Granville, Ohio.
HIRAM COLLEGE, Hiram, Ohio.
OBERLIN COLLEGE, Oberlin, Ohio.
OTTERBEIN COLLEGE, Westerville, Ohio.
THE COLLEGE OF WOOSTER, Wooster, Ohio.
ANTIOCH COLLEGE, Yellow Springs, Ohio.

OKLAHOMA

UNIVERSITY OF OKLAHOMA, Norman, Okla.

OREGON

UNIVERSITY OF OREGON, Eugene, Ore.

PENNSYLVANIA

BRYN MAWR COLLEGE, Bryn Mawr, Pa.
LAFAYETTE COLLEGE, Easton, Pa.
SETON HILL COLLEGE, Greensburg, Pa.
ALLEGHENY COLLEGE, Meadville, Pa.
ALBRIGHT COLLEGE, Myerstown, Pa.
THE DREXEL INSTITUTE, Philadelphia, Pa.
SWARTHMORE COLLEGE, Swarthmore, Pa.
WASHINGTON AND JEFFERSON COLLEGE, Washington, Pa.

RHODE ISLAND

BROWN UNIVERSITY, Providence, R. I.
RHODE ISLAND COLLEGE OF EDUCATION, Providence, R. I.

SOUTH CAROLINA

UNIVERSITY OF SOUTH CAROLINA, Columbia, S. C.

SOUTH DAKOTA

NORTHERN NORMAL AND INDUSTRIAL SCHOOL, Aberdeen, S. D.

TENNESSEE

VANDERBILT UNIVERSITY, Nashville, Tenn.

TEXAS

WEST TEXAS STATE TEACHERS COLLEGE, Canyon, Tex.
SOUTHERN METHODIST UNIVERSITY, Dallas, Tex.
RICE INSTITUTE, Houston, Tex.
BAYLOR UNIVERSITY, Waco, Tex.

UTAH

UNIVERSITY OF UTAH, Salt Lake City, Utah.

VERMONT

MIDDLEBURY COLLEGE, Middlebury, Vt.

VIRGINIA

VIRGINIA POLYTECHNIC INSTITUTE, Blacksburg, Va.
UNIVERSITY OF VIRGINIA, University, Va.
COLLEGE OF WILLIAM AND MARY, Williamsburg, Va.

WASHINGTON

UNIVERSITY OF WASHINGTON, Seattle, Wash.

WEST VIRGINIA

BETHANY COLLEGE, Bethany, W. Va.

WYOMING

UNIVERSITY OF WYOMING, Laramie, Wyo.

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ALABAMA. (16)

ATHENS. J. Stone.
AUBURN. Crenshaw, Killebrew.
BIRMINGHAM. Balof, Eagles, Hess, W. A. Moore, Sewell.
FLORENCE. Culmer.
MONTEVALLO. Mears.
ROANOKE, Mickle.
TUSCALOOSA. Nixon.
UNION SPRINGS. Lee.
UNIVERSITY. Dahlene, F. A. Lewis, Ott.

ARIZONA. (6)

FLAGSTAFF. Lampland.
TUCSON. Atkinson, Cresse, Graesser, H. B. Leonard, Purcell.

ARKANSAS. (9)

ARKADELPHIA. Garretson.
BATESVILLE. S. W. Williams.
FAYETTEVILLE. Droke, A. M. Harding, J. C. Hughes, G. D. Nichols.
LITTLE ROCK. Bigbee, d'Unger.
SEARCY. B. R. Allen.

CALIFORNIA. (94)

ATASCADERO. H. E. Anderson, Schmiedel.
BAKERSFIELD. Powelson, Sagen.
BERKELEY. Bernstein, Cajori, M. W. Haskell, Irwin, Lehmer, S. H. Levy, McCarty, McDonald, Noble, T. M. Putnam, P. Sperry, A. R. Williams, Wong.
CHICO. Iloff.
CLAREMONT. G. E. Berry, W. P. Russell.
DAVIS. Titus.
FRESNO. F. R. Morris.
FULLERTON. L. E. Reynolds.
GLENDALE. Bolton, Prater.
HOLLYWOOD. Entz.
LA JOLLA. G. F. McEwen.
LONG BEACH. Lodwick.
LOS ANGELES. E. E. Allen, Ames, C. Bell, J. R. Campbell, Collier, Daus, Gaver, Glazier, Hedrick, G. H. Hunt, James, McClellan, W. E. Mason, Reinert, Sherwood, Showman, D. V. Steed, Touton, Willett, Worthington.
LOS GATOS. Stager.
MARE ISLAND. See.
MILLS COLLEGE. Alderton.
MODESTO. Pobanz.
MT. HAMILTON. Jeffers.
OAKLAND. G. E. Allen, F. M. Gibson.
ORLAND. Fenner.
PALO ALTO. Biggerstaff, Hoskins, R. L. Jackson.
PASADENA. Basoco, Bateman, E. T. Bell, Birchby, Hicks, Meek, C. B. Millikan, W. A. Newlin, Podolsky, Stoner, Sturdivant, Van Buskirk, M. Ward, Wear, C. Wolfe.
PIEDMONT. Stafford.
POINT LOMA. Dick.
REDLANDS. O. W. Albert, Keith.
RIVERSIDE. Linhart.
SACRAMENTO. Wallace.
SALINAS. Walter.
SAN DIEGO. Klauber, Livingston.
SAN FRANCISCO. Libby.
SANTA ANA. Whiting.
SANTA MARIA. Funk.
STANFORD UNIVERSITY. Blichfeldt, W. L. Crum, Eells, Green, Moreno.
STOCKTON. Corbin.
VENICE. W. A. Austin.
WHITTIER. Skarstedt.

CANADA. (37)

CALGARY. F. G. Young.
EDMONTON SOUTH. J. W. Campbell, Sheldon.
HALIFAX. F. H. Murray.
KINGSTON. Gummer, K. P. Johnston, Matheson, N. Miller, Twiss.
LENOXVILLE. A. V. Richardson.
LONDON. Kingston.
MONTREAL. Beaupré, D. A. Murray, Pelletier.
OTTAWA. Dube, Henroteau.
POINT GREY. E. E. Jordan.
PORT COLBORNE. Kinnear.
QUEBEC. Savary, Tremblay.
RED DEER. A. A. Grant.
REGINA. McEwen.
SASKATOON. Ling, Pyke.
TORONTO. Beatty, De Lury, Fields, Findlay, Pounder, Rosebrugh, Skirrow.
VANCOUVER. D. Buchanan, G. E. Robinson.
VICTORIA. Gage.
WINNIPEG. T. H. Milne, Warren, N. R. Wilson.

COLORADO. (29)

BOULDER. De Long, Hutchinson, Jekel, Kempner, Kendall, Lester, Light, McGinley, W. K. Nelson.
CANON CITY. McNatt.
COLORADO SPRINGS. Albright, Lovitt, Sisam.
DENVER. F. L. Carmichael, E. A. Cummings, Fenton, P. Fitch, Gorrell, Odell, Sabin, Wray.
FORT COLLINS. A. G. Clark, S. L. Macdonald.
GOLDEN. J. R. Everett, Martinson, Risley.
GREELEY. Finley.

GUNNISON. Ankebrant.
WHEATRIDGE. A. J. Lewis.

CONNECTICUT. (32)

BRIDGEPORT. M. G. Haseman.
GREENWICH. R. H. Hall.
HARTFORD. A. H. Andrews, Burkett, Dadourian, C. H. Davis, Elston, Flynn, E. B. Morris, Spaulding, Welling.
MIDDLETOWN. H. E. Arnold, B. H. Camp, Howland.
MILFORD. Rosenbaum.
NEW HAVEN. Barney, E. W. Brown, H. T. Burgess, Fisher, Gehman, Kovarik, Longley, Miles, L. T. Moore, H. Thompson, Tracey, Uhler, Whittemore, W. A. Wilson.
NEW LONDON. Leib.
SALES FERRY. Dimick.
WEST HAVEN. Shook.

DELAWARE. (7)

LAUREL. C. A. Short.
NEWARK. Boeder, Harter, Lerch, C. J. Rees.
WILMINGTON. Gardner, R. W. Jones.

DISTRICT OF COLUMBIA. (46)

BROOKLAND. Landry.
WASHINGTON. O. S. Adams, Arnaud, Ashmun, Avers, L. A. Bauer, W. J. Berry, Bixby, Breit, Burley, Cromwell, Dantzig, Darling, Duerksen, H. English, Erwin, Federico, J. F. Fox, Garner, Goldberg, W. M. Hamilton, Hodgkins, Kaufman, Keulegan, W. D. Lambert, Lemon, Mangold, McKnight, E. C. Phillips, Ramler, J. N. Rice, Richmond, Roeser, Ross, Shenton, Stevens, E. R. Thompson, Tomelden, Van Orstrand, Wallis, C. B. Watts, Wernicke, J. E. Willis, E. W. Wilson, Woodard, Woolard.

FLORIDA. (12)

APOPKA. Larson.
CENTER HILL. Frary.
GAINESVILLE. Chandler, Dostal, Higgins, Kokomoor, Kusner, C. A. Messick, T. M. Simpson.
MIAMI. Searle.
TALLAHASSEE. Elmer R. Smith.
WINTER PARK. Weinberg.

GEORGIA. (27)

ATHENS. Barrow, W. S. Beckwith, Cumming, P. R. Hill, R. P. Stephens.
ATLANTA. Benander, Fulmer, G. K. Howe, Morton, Patton, M. R. Richardson, Skiles, D. M. Smith.
DECATUR. F. Field, L. J. Gaylord, Parker, H. A. Robinson.
DEMOREST. J. C. Rogers.
EMORY UNIVERSITY. Messick, Rumble.
GAINESVILLE. Allison.
LA GRANGE. E. A. Bailey.
MACON. Day, Holder, Plymale, F. Wood.
ROME. Hightower.
WAYCROSS. A. R. Walton.

HAWAII. (1)

HONOLULU. Donaghho.

IDAHO. (4)

CALDWELL. J. M. Rankin, I. White.
MOSCOW. E. Taylor.
POCATELLO. Galloway.

ILLINOIS. (130)

ALTON. Denman.
ATWOOD. Hobart (?).
BELLWOOD. M. Hildebrandt.
BLOOMINGTON. M. Hunt.
BLUFFS. C. C. Carter.
CARLINVILLE. Renner.
CARTHAGE. Van Velzer.
CHAMPAIGN. H. W. Bailey, G. E. Moore.
CHARLESTON. Modesitt, E. H. Taylor.
CHICAGO. C. W. Andrews, Barnard, Bartky, Beenken, Bibb, Bliss, Burroughs, Cobb, Cope, Dickson, H. S. Everett, Feltges, Z. Ferguson, Georges, Ghormley, Granville, L. M. Graves, Jarrett, Jenkins, B. W. Jones, Kinney, Krathwohl, Kurzin, Lane, Lange, Laves, Logsdon, Lunn, MacMillan, E. H. Moore, F. R. Moulton, Muehlman, G. W. Myers, Nicolet, Nyberg, C. I. Palmer, Pettersen, Plapp, C. A. Rupp, Scharf, Schottenfels, Schweitzer, Shaw, Slaught, E. L. Thompson, Werkman, Whaley, J. W. A. Young.
CICERO. B. A. Rogers.
DECATUR. Kiefer.
DE KALB. G. H. Freeman, Parson.
EUREKA. Newson.
EVANSTON. V. M. Andrews, O. E. Brown, D. F. Campbell, Curtiss, H. L. Garabedian, Holgate, E. J. Moulton, Newell, Olson, Simmons, Westcott, F. E. Wood.
FREEPORT. Eichelberger, M. C. Martin, Mensenkamp.
GALESBURG. Heren, Sellew, M. E. Taylor.
GODFREY. Freas.
GURNEE. N. M. Johnston.
JACKSONVILLE. M. Anderson, E. B. Miller.
LAKE FOREST. Curtis.
LA SALLE. L. H. Brown, Carus.
LEBANON. Stowell.
LINCOLN. Denny.
LISLE. Fleisig.
MACOMB. Ginnings.
MONMOUTH. Winbigler.
MONTICELLO. Wolever.
MOUNT MORRIS. L. S. Shively.
NAPERVILLE. Coultrap.
NORMAL. Atkin, Flagg, C. N. Mills.
OAK PARK. Escott, Richards.
ORLEANS. J. T. Holmes.
PEORIA. Comstock, Gaut.
RIVER FOREST. Dobbin.
ROCKFORD. McGavock, B. I. Miller.
ROCK ISLAND. Cederberg, Sheets.
ROCKTON. Bigelow.
TAYLORVILLE. Dappert.

URBANA. B. M. Armstrong, Bender, T. L. Bennett, R. D. Carmichael, Crathorne, Emch, F. Harshbarger, Hazlett, F. E. Johnston, H. Levy, Libman, Lytle, G. A. Miller, Steimley, Townsend, A. L. Young.
WHEATON. Garlough, Hillard.

INDIANA. (52)

BLOOMINGTON. H. T. Davis, Davisson, Hanna, Hennel, Rothrock, K. P. Williams, H. E. Wolfe.
COLUMBIA CITY. Knisely.
CRAWFORDSVILLE. Carscallen, Cragwall.
CULVER. R. E. Peterson.
DANVILLE. Cole.
EARLHAM. F. Long.
ELWOOD. R. N. Haskell.
GOSHEN. Lehman.
GREENCASTLE. Arnold, Greenleaf.
HANOVER. Zinszer.
INDIANAPOLIS. Aley, Banes, Diederich, E. N. Johnson, J. M. Lutz, Mathias.
LAFAYETTE. Marshall, Mason.
MT. VERNON. Blackburn.
MUNCIE. Edwards.
NORTH MANCHESTER. Dotterer.
NOTRE DAME. Caparo, Hull, McCue, Maurus.
OAKLAND CITY. W. Jordan.
RICHMOND. E. D. Grant, H. N. Wright.
TERRE HAUTE. Kennedy, Sousley.
WESTFIELD. E. H. Johnson.
WEST LAFAYETTE. Bolks, Copp, Doan, Edington, G. H. Graves, Hadley, Hazard, Hodge, Robbins, Stauffer, R. B. Stone, Stout, Zehring.

IOWA. (49)

AMES. Brandner, Colpitts, Daniells, Fleming, Gouwens, J. V. McKelvey, M. M. McKelvey, M. M. Roberts, E. R. Smith, Snedecor, J. S. Turner.
CEDAR FALLS. Condit, Kearney, Wester.
CEDAR RAPIDS. L. M. Coffin, Yothers.
DECORAH. Strom.
DES MOINES. Blom, Corey, Neff, Wifvat.
DUBUQUE. Theobald, Zimmerman.
FAYETTE. Deming.
GRINNELL. McClenon, Rusk.
HOPKINTON. Earhart.
INDIANOLA. C. W. Emmons.
IOWA CITY. F. E. Baker, R. P. Baker, Chittenden, Conkwright, Y. V. Maizlish, Reilly, Rietz, L. E. Ward, R. Woods, Wylie.
LE MARS. Blue.
MOUNT VERNON. McGaw, Moots.
OSKALOOSA. S. M. Hadley.
SILVER CITY. Paul.
SIOUX CITY. Graber, Gwinn, Van Horne.
STORM LAKE. Reusser.
WEBSTER CITY. H. L. Rice.
WELLMAN. Kreth.

KANSAS. (49)

BALDWIN CITY. P. L. Evans, Garrett.
COFFEYVILLE. Steininger.
EMPORIA. Phillips, Rumney.
HAYS. Colyer.
HESSTON. Driver.
HIGHLAND. T. B. Henry.
INDEPENDENCE. A. M. Austin.
IOLA. R. H. Carpenter.
KANSAS CITY. Dougherty, Helwig.
LAWRENCE. Ashton, Babcock, Black, H. E. Jordan, Marm, U. G. Mitchell, G. W. Smith, Stouffer, J. J. Wheeler.
MANHATTAN. W. H. Andrews, Holroyd, Hyde, Janes, R. E. Leonard, C. F. Lewis, Lyons, Mossman, T. I. Porter, Remick, Stratton, A. E. White.
NEWTON. Richert.
OTTAWA. J. L. Bennett, Loewen.
PARSONS. Farner.
PITTSBURG. R. W. Hart, W. H. Hill, Shirk.
STERLING. T. Bell.
TOPEKA. Croom, Harshbarger, McLatchey.
WICHITA. Hoare, Longenecker, Mendenhall, Reagan.
WINFIELD. H. S. Myers.

KENTUCKY. (18)

BEREA. Hutcherson, T. A. Martin.
DANVILLE. Fehn, [illegible]
GEORGETOWN. Clayton, C. H. Richardson.
LEXINGTON. Boyd, M. E. Clarke, J. M. Davis, Downing, Latimer, Le Stourgeon, Maney, E. L. Rees. [illegible]
LOUISVILLE. Bullitt, Stevenson, Vance.
PARIS. F. A. Scott.
WINCHESTER. Dearman.

LOUISIANA. (32)

ALEXANDRIA. Kilpatrick, Longmire, Touchstone.
BATON ROUGE. Daspit, Guilbeau, Nichols, O'Quinn, S. T. Sanders, H. L. Smith, Webber, Welch.
CLINTON. Petty.
NATCHITOCHES. L. Blair, Killen, Maddox.
NEW ORLEANS. H. E. Buchanan, Dinwiddie, Duren, Frankenbush, A. M. Howe, Many, McShane, Menuet, J. H. Meyer, Rothfuss, Spencer, H. L. Titsworth.
PINEVILLE. C. D. Smith.
SHREVEPORT. Hardin, I. Maizlish, Mauldin.
SLIDELL. Gaulden.

MAINE. (11)

BRUNSWICK. Hammond, Moody.
LEWISTON. Ramsdell, Wilkins.
ORONO. Bryan, Hadlock, J. N. Hart, M. F. Jordan, W. P. Morse.
WATERVILLE. Ashcraft, Trefethen.

MARYLAND. (51)

ABERDEEN. Dederick.
ANNAPOLIS. Bingley, Bramble, Bullard, Capron, Clements, Dillingham, Eppes, Garrison, Hemke, Kells, Leiper, Mayer, Rawlins, Robert, Root, J. B. Scarborough, J. Tyler.

BALTIMORE,. Aitchison, Bacon, Bassler, Blumenthal, Cary, Coble, Cohen, C. W. R. Crum, Gwinner, Hallam, Harry, Hulburt, F. P. Lewis, A. K. Mitchell, W. K. Morrill, T. W. Moore, F. Morley, Murnaghan, Musselman, Peters, L. J. Reed, Richeson, Thomsen, Torrey.
CHELTENHAM. Hartnell.
CHESTERTOWN. J. S. W. Jones.
COLLEGE PARK. Spann, T. H. Taliaferro.
EMMITSBURG. Burke.
FREDERICK. K. S. Arnold, L. O. Brown.
ROLAND PARK. Morrow.
WESTMINSTER. B. I. Hart.

MASSACHUSETTS. (103)

AMHERST. Esty, F. C. Moore, Olds, C. S. Porter.
ANDOVER. F. E. Newton.
BELMONT. Douglass, Downey, Rutledge.
BOSTON. Brigham, Bruce, H. D. Gaylord, Gould, Holbrook, Laurentine, Leary, Lucey, Marsh, Mode, Osborne, M. M. Smith, Spear, Edwin B. Wilson.
BROOKLINE. Andrew, A. L. Miller, Washburn.
CAMBRIDGE. F. H. Bailey, Beatley, Birkhoff, Bradley, T. H. Brown, Coolidge, A. H. Fox, Franklin, Graustein, Hollis, E. V. Huntington, Kellogg, Kennelly, Lubin, C. L. E. Moore, M. Morse, Osgood, Passano, F. W. Perkins, J. K. Peterson, H. B. Phillips, Poritsky, Price, L. H. Rice, H. W. Tyler, Walsh, D. E. Whitford, F. S. Woods, F. W. Wright, Zeldin.
DANVERS. Majella.
DORCHESTER. J. W. Davis, Quigley.
EAST NORTHFIELD. Daboll.
EVERETT. Bryant.
FRAMINGHAM. Bickford.
GLOUCESTER. MacNutt.
HOLYOKE. Moriarty.
LAWRENCE. Lord.
LYNN. G. W. Evans.
MEDFORD. Cheney.
NATICK. Nutt, R. Willis.
NORTHAMPTON. Anderton, S. R. Benedict, Eversull, Munroe, Rambo, R. G. Wood.
PITTSFIELD. Washburne.
SHEFFIELD. Eipper.
SOUTH HADLEY. Doak, E. N. Martin, S. E. Smith.
SPRINGFIELD. S. E. Cook, Hickox.
TUFTS COLLEGE. Mergendahl, Ransom.
WELLESLEY. Copeland, Doughty, Merrill, C. E. Smith, Stark, Vivian, M. M. Young.
WESTON. O'Donnell.
WILLIAMSTOWN. Agard, Hardy, V. H. Wells.
WOLLASTON. Dennison. Gardner.
WORCESTER. E. C. Brown, Gay, Melville, R. K. Morley, H. Rice, A. H. Wheeler, F. B. Williams.

MICHIGAN. (66)

ALBION. Evers, F. E. Field, Sleight.
ALMA. Clack.
ANN ARBOR. Anning, Bradshaw, Coe, Craig, Denton, P. Field, S. E. Field, W. B. Ford, J. W. Glover, T. H. Hildebrandt, Hopkins, H. K. Hughes, Karpinski, Kazarinoff, Love, Markley, Newsom, Nyswander, O. J. Peterson, Poor, Raiford, Rainich, Rood, Rouse, Running, Schorling, Schreiber, Shohat, R. L. Wilder, Ziwet.
BAY CITY. Shellenberger.
DETROIT. Baldwin, Borgman, Chalmers, Darnell, Frumveller, Mullen, A. L. Nelson, Paula, Thome.
EAST LANSING. Crowe, L. C. Emmons, V. G. Grove, H. L. Olson, Plant, Powell, Speeker.
HILLSDALE. Herron, Penrod.
HOLLAND. Lampen.
KALAMAZOO. H. Blair, J. P. Everett, T. O. Walton.
MARQUETTE. Spooner.
MOUNT PLEASANT. Pearce.
ROYAL OAK. Schoonover.
SPRING ARBOR. M. G. Smith.
STURGIS. Steirnagle.
YPSILANTI. Barnhill, Lindquist, Lyman, Matteson.

MINNESOTA. (41)

COLLEGEVILLE. Winklemann.
DULUTH. Morin.
MANKATO. Chapman, A. V. Robbins.
MINNEAPOLIS. Beal, Brink, Brooke, Bussey, S. E. Carlson, Dalaker, Earl, Gibbens, W. L. Hart, Hartig, D. Jackson, Jensen, Kirchner, Ness, Priester, Risselman, Scammon, Shuman, Shumway, Thorp, Underhill, E. D. Wells, Wilcox.
MOOREHEAD. K. Leonard.
NORTHFIELD. Gingrich, Nordgaard, Solum, M. B. White.
ST. PAUL. Alice Irene, Kingery, Kyes, Moench, W. D. Morgan, Reuterdahl, F. J. Taylor.
ST. PETER. Rundstrom.
VIRGINIA. C. L. Hancock.
WINONA. Bogard.

MISSISSIPPI. (14)

A. AND M. COLLEGE. H. Fox, B. M. Walker.
BLUE MOUNTAIN. Hutchins.
CLEVELAND. Dale.
GRENADA. M. E. Harris.
HATTIESBURG. P. K. Smith.
JACKSON. Babbitt, B. E. Mitchell, Smylie.
MERIDIAN. I. K. Smith.
STARKVILLE. A Edmondson.
UNIVERSITY. Hume, Wunder.
VICKSBURG. M. L. Newton.

MISSOURI. (46)

AXTELL. Epperson.
CANTON. B. Ingold.
CAPE GIRARDEAU. B. F. Johnson, Knepper.
CARTHAGE. Murto, Edna Robinson.
CLAYTON. Haertter.
COLUMBIA. E. F. Allen, Callaway, Ingold, Jaeger, Wahlin, W. D. A. Westfall, Wyant.
FULTON. Sweazey, M. A. Wood.

JOPLIN. E. M. Weaver.
KANSAS CITY. Cutting, Luby, F. L. Marshall, Pierson.
KIRKSVILLE. Cosby, Jamison.
LIBERTY. Fleet.
MAYSVILLE. Saunders.
PARKVILLE. R. A. Wells.
ROLLA. Hinsch.
SPRINGFIELD. Finkel, E. M. Gibson.
ST. CHARLES. Karr.
ST. JOSEPH. Burney.
ST. LOUIS. Ammerman, Dunkel, Gerst, A. H. Huntington, King, Nauer, Osborn, Rider, Roever, Shannon, E. Stephens, Tracy, J. M. Young.
TARKIO. Jenison.
WARRENSBURG. J. H. Scarborough.
WEBSTER GROVES. M. B. Clarke.

MONTANA. (7)

BUTTE. Bowersox.
GLASGOW. Calderwood.
HELENA. Canning, Wible.
MISSOULA. Carey, Lennes, A. S. Merrill.

NEBRASKA. (22)

BURWELL. Opp.
CERESCO. L. C. Walker.
CRETE. J. M. Hawkes.
GRAND ISLAND. H. Anderson.
HASTINGS. McDill.
KEARNEY. Hanthorn.
LINCOLN. Brenke, C. C. Camp, Candy, Congdon, Gaba, Gossard, Howie, M. F. Jackson, T. A. Pierce, Runge.
OMAHA. Bettinger, H. A. Campbell, Frankish, Wilmer.
PERU. A. L. Hill.
YORK. Feemster.

NEVADA. (1)

RENO. C. Haseman.

NEW HAMPSHIRE. (15)

CONCORD. G. M. Conwell.
DURHAM. G. N. Bauer, Slobin, Wilbur.
EXETER. Barber, Sweet.
HANOVER. Beetle, Bill, B. H. Brown, Forsyth, Mathewson, Morgan, Silverman, C. E. Wilder, J. W. Young.

NEW JERSEY. (42)

BELLEPLAIN. Durell.
BRIDGETON. J. M. Rice.
CONVENT STATION. Maskell.
CRANFORD. Knedler.
EAST ORANGE. Koch, Mallory, F. H. Robinson, Stanwick.
LAWRENCEVILLE. Kimball, Mikesh.
LEONIA. Gafafer, M. S. Taylor.
MOORESTOWN. R. R. Wood.
MORRIS PLAINS. A. E. Johnson.
NEWARK. Conkling.
NEW BRUNSWICK. F. C. Hall, Huber, Meder, R. Morris, C. A. Nelson, R. Thompson, A. A. Titsworth, C. R. Wilson.
PATERSON. Caster.
PRINCETON. E. P. Adams, Alexander, Cramlet, Eisenhart, Fine, D. A. Flanders, W. Gillespie, Hille, Knebelman, Lefschetz, P. M. Morse, Veblen, Wedderburn, A. P. Wheeler, Willson.
RUTHERFORD. McMackin.
SOMERVILLE. Moyle.
TRENTON. Colliton.

NEW MEXICO. (5)

ALBUQUERQUE. Barnhart.
EAST LAS VEGAS. Rodgers.
MONTEZUMA. Barrick.
SILVER CITY. Hunter.
SOCORRO. Reece.

NEW YORK. (190)

ALBANY. Birchenough, Do Bell.
ALFRED. Seidlin, W. A. Titsworth.
ANNANDALE-ON-HUDSON. Phalen.
AURORA. Hollcroft.
BALDWIN. C. C. Grove.
BRONX. Tanzola, Weisner.
BROOKLYN. Angelica, Bergstresser, W. J. Berry, Bowden, Emery, Fleisher, Kreines, Langman, Lehmann, Locke, Schuyler, Shorr, Thecla, J. E. Thompson.
BUFFALO. Archer, Cusick, Harrington, Pound, Sherk, M. Watt.
CLINTON. H. S. Brown, Carruth, Ferry, A. L. Fitch, Patterson.
CORONA. Hanson.
ELMIRA. Suffa, F. M. Wright.
FLUSHING. P. H. Graham, Oglesby.
FRIENDSHIP. O'Kean.
GENEVA. W. H. Durfee, W. P. Durfee, Hubbs.
HAMILTON. Aude, W. B. Campbell, A. W. Smith.
ITHACA. Agnew, Beisel, Boothroyd, Carver, H. A. Davis, Dye, D. C. Gillespie, Hurwitz, Jeffery, Karapetoff, Lowenstein, Ranum, Schoonmaker, V. Snyder, Torrance, F. G. Williams.
JAMAICA. Barrett.
MOUNT VERNON. Breckenridge.
NEWBURGH. C. W. Miller.
NEW YORK. J. Allen, Auerbach, Beiler, Berger, Berkeley, V. Blair, W. M. Bond, Brahdy, Brewster, Burdick, R. W. Burgess, G. A. Campbell, J. R. Clark, R. F. Clark, J. G. Coffin, Cooley, Eckersley, Edmonson, Eisele, O. Everett, Farnum, Fiske, Fite, Foster, Frankel, Fry, Gill, Harper, Hawkes, R. Henderson, Himwich, Hirsch, Hodgdon, Hoyt, Jablonower, Joffe, M. I. Johnson, R. A. Johnson, P. C. Jones, Kasner, Kunte, Larkin, Linehan, Littauer, H. L. Lutz, MacGregor, Maiden, Mirick, Molina, Mullins, Paaswell, Packer, Payne, Pedersen, Penn, Pooler, Post, Pride, Quilty, Reddick, Reeve, Ritt, Rosanoff, Sanford, Saurel, Schmall, Schub, Shewhart, Siceloff, Simons, D. E. Smith, R. F. Smith, R. R. Smith, Spies, Thorne, Tilley, A. B. Turner, Upton, E. Walker, H. M. Walker, Wechsler, Werner, E. E. Whitford, Woodyard.

NISKAYUNA. Male.
OLEAN. Lowry.
PARISH. Church.
POTSDAM. Isham.
POUGHKEEPSIE. Cowley, L. D. Cummings, J. P. Smith, M. E. Wells.
RICHMOND HILL. F. H. Miller.
ROCHESTER. Betz, Gale, Garver, H. Harding, T. R. Long, Silberstein, Watkeys, Welton.
SCARSDALE. MacNeish.
SCHENECTADY. Caruthers, Hussey, D. S. Morse, Newkirk, A. D. Snyder, Stokes, Ulrich, Vedder.
SYRACUSE. A. D. Campbell, Carroll, Decker, Lindsey, Secy. Pi Mu Epsilon Frat., Roe, M. Sperry, W. E. Taylor, Warne.
TARRYTOWN. R. G. Putnam.
TROY. Crockett.
WEST POINT. C. P. Echols.
YONKERS. Hubert, John, Yanosik.

NORTH CAROLINA. (24)

CHAPEL HILL. Browne, Cain, A. Henderson, M. A. Hill, Hobbs, Lasley, Mackie.
CHARLOTTE. O. M. Jones, Woodson.
DAVIDSON. J. L. Douglas.
DURHAM. Elliott, W. W. Rankin, Robison.
ELIZABETH CITY. C. F. Holmes.
ELON COLLEGE. Amick.
GREENSBORO. Barton, Pegram, Strong, Watkins.
GREENVILLE. M. D. Graham.
JAMESTOWN. Ragsdale.
MARS HILL. W. F. Robinson.
MURFREESBORO. Caldwell.
RED SPRINGS. Shuler.

NORTH DAKOTA (4).

FARGO. Householder.
GRAND FORKS. Staley.
UNIVERSITY. Hitchcock.
VALLEY CITY. J. B. Meyer.

OHIO. (104)

ADA. Fairchild, Whitted.
AKRON. Reger.
ATHENS. Borger, F. W. Reed.
BEREA. Baur, Dustheimer.
BOWLING GREEN. Overman.
BLUFFTON. Hirschler.
CINCINNATI. I. A. Barnett, Brand, C. A. Garabedian, H. Hancock, Justice, Kersten, Kindle, C. N. Moore, Mullings, C. E. Rhodes, Salkover, E. S. Smith, E. V. Watts, Wilczewski, Yowell.
CLEVELAND. Boyce, Burington, Focke, W. W. Johnson, Justin, J. E. Merrill, M. Morris, Nassau, Palmié, Simon, C. F. Thomas, Trofimov.
COLUMBUS. C. L. Arnold, Atwater, Bareis, Beatty, H. Blumberg, Bumer, V. B. Caris, Harmount, Horn, R. S. Kimball, Kuhn, MacDuffee, Manson, Michal, C. C. Morris, Preston, Rasor, Rickard, B. Saunders, Singer, Wildermuth.
DAYTON. Hartwick.
DEFIANCE. A. G. Caris.
DELAWARE. Crane, R. L. Newlin, Rowland.
GAMBIER. R. B. Allen, Redditt.
GRANVILLE. E. C. Rupp, F. B. Wiley.
HILLIARD. J. H. Weaver.
HIRAM. E. H. Clarke, Jerome.
KENT. N. B. Freeman, Manchester.
MACEDONIA. Burwell.
MARIETTA. Coar, Rea.
MOUNT ST. JOSEPH. Molloy.
NEW CONCORD. C. E. White.
OBERLIN. Battig, R. L. Brown, Cairns, Carr, M. M. Johnson, Sinclair, Yeaton.
OXFORD. J. P. Albert, W. E. Anderson, Baudin, Erickson, Pollard, Spenceley, Tappan.
PAINESVILLE. A. D. Lewis.
Ross. Haldeman.
SPRINGFIELD. Tripp.
TIFFIN. J. Pierce.
TOLEDO. Brandeberry, Mercedes, Winslow.
WESTERVILLE. B. C. Glover.
WILBERFORCE. Tinner.
WILMINGTON. Spinks.
WOOSTER. L. C. Knight, Williamson, Yanney.
ZANESVILLE. Riesbeck.

OKLAHOMA. (25)

ADA. K. K. Knight.
ALVA. H. L. Hall.
CHICKASHA. J. J. Miller.
MIAMI. C. S. Whitney.
NORMAN. Brixey, Court, Hampton, Hassler, D. McFarland, E. McFarland, Meacham, Raynor, S. W. Reaves.
OKMULGEE. Thom.
SHAWNEE. W. T. Short.
STILLWATER. R. L. Flanders, Gundersen, H. W. Smith.
TULSA. Byrd, W. E. Howard, H. F. Mitchell, Roman, Rutherford, G. R. West.
WEATHERFORD. McCormick.

OREGON (14)

ALBANY. Butler.
CORVALLIS. Beaty, C. L. Johnson, Van Fleet, G. A. Williams.
EUGENE. D. R. Davis, De Cou, McAlister, W. E. Milne.
MCMINNVILLE. M. Ramsey.
PENDLETON, J. A. Carlson.
PORTLAND. Griffin, Merriss, J. M. Short.

PENNSYLVANIA. (105)

ALLENTOWN. Bauman.
ANNVILLE. P. S. Wagner.
ARDMORE. M. H. Macdonald.
BALA. Gummere.
BEAVER FALLS. Cleland.
BETHLEHEM. L. S. Barnes, Fort, Lamson, McDonough, Paradiso, Rau, J. B. Reynolds, Smail, Weida.
CAMP HILL. Foberg.
CARLISLE. Landis.
CHESTER. Holt.
COLLEGEVILLE. Clawson, Veatch.

CYNWYD. Sensenig.
DEVON. J. A. Clarke.
EASTON. Doushkess, W. S. Hall, Hatch, Marquard, W. M. Smith.
GROVE CITY. A. Ramsey.
HARRISBURG. Whited.
HAVERFORD. L. W. Reid, A. H. Wilson.
HUNTINGTON. C. S. Shively.
IRWIN. A. A. Jones.
LANCASTER. R. L. Charles, W. F. Long.
LANSDOWNE. Chambers, Glenn.
LATROBE. Seubert.
LEWISBURG. Gold, Lindemann, MacCreadie.
LINCOLN UNIVERSITY. W. L. Wright.
LOCK HAVEN. High, Smink.
MARCUS HOOK. H. M. Manning.
MEADVILLE. Akers.
MILLERSVILLE. Seiverling.
NEW WILMINGTON. McCain.
PHILADELPHIA. Adkisson, P. A. Caris, Crawley, J. E. Davis, Eshleman, H. B. Evans, F. H. Jackson, Kline, Linton, Lufkin, H. H. Mitchell, Oergel, Partridge, Rittenhouse, W. Roberts, Rosengarten, Rothermel, Safford.
PITTSBURGH. Baird, Bishop, Geckeler, R. P. Johnson, J. H. Mathews, Minister, Moskowitz, Neelley, E. G. Olds, Riggs, Rosenbach, Swartzel, Taber, J. S. Taylor, Waltz, Whitman.
SEWICKLEY. W. I. Miller.
SHIPPENSBURG. Kieffer.
STATE COLLEGE. Bushyager, T. Cohen, Gravatt, L. S. Johnston, E. D. McCarthy, F. W. Owens, H. B. Owens, Shibli, Stetson, J. M. West.
SWARTHMORE. Dresden, Marriott, J. A. Miller, Pitman.
SWISSVALE. Foraker.
WASHINGTON. Atchison, Bert, Rasel, Shaub, R. W. Thomas.
WEST PHILADELPHIA. Latshaw.
WILLIAMSPORT. Hoshauer.

PANAMA. (1)

PANAMA CITY. Linares.

PHILLIPPINE ISLANDS. (5)

LAGUNA. Salvosa.
MANILA. Jimenez, V. Mills, Tan, Tienzo.

PORTO RICO. (3)

MAYAGUEZ. Sanchez.
RIO PEDRAS. Horne.
SAN JUAN. Betancourt del Valle.

RHODE ISLAND. (15)

APPONAUG. Vehse.
NEWPORT. Chase.
PROVIDENCE. C. R. Adams, Archibald, A. A. Bennett, Carlen, Chace, Currier, Gilman, Hickson, H. P. Manning, R. G. D. Richardson, Suesman, Tamarkin, M. W. Watt.

SOUTH CAROLINA. (14)

CHARLESTON. O. J. Bond, R. H. Coleman.
COLUMBIA. Coker, J. B. Coleman, J. B. Jackson, Moorefield, Peele, W. L. Williams.
GREENVILLE. Bowen, Earle, R. B. Wood.
GREENWOOD. Weber.
HARTSVILLE. C. M. Reaves.
ROCK HILL. G. T. Pugh.
SALUDA. Ramage.

SOUTH DAKOTA. (8)

BROOKINGS. Gore, I. L. Miller.
HURON. Titt.
MITCHELL. Knox.
RAPID CITY. Bowles.
SPEARFISH. Hesseltine.
VERMILLION. McKinney.
YANKTON. Faught.

TENNESSEE. (17)

CHATTANOOGA. Perry.
CLEVELAND. Ryno.
HARROGATE. Hatfield.
JACKSON. E. L. Carr, Walden.
JEFFERSON CITY. E. W. White.
KNOXVILLE. Baten, J. D. Bond, Brezler.
MARYVILLE. Knapp.
NASHVILLE. R. V. Blair, S. I. Jones, N. P. Miser, W. L. Miser, Wren.
NORMAL. P. L. Armstrong.
PULASKI. Mize.

TEXAS. (87)

ABILENE. Burnam, Tate.
ALPINE. Gilley.
ARANSAS PASS. W. N. Barnes.
AUSTIN. W. L. Ayres, Batchelder, H. Y. Benedict, Blau, Cooper, Decherd, Dodd, Dorroh, Duncan, Ettlinger, H. L. Holmes, Horton, Jacobs, Lubben, D. E. Mitchell, R. L. Moore, M. B. Porter, W. T. Reid, J. H. Roberts, Simester, Vandiver.
BENAVIDES. Pickett.
BOERNE. Hathaway.
BROWNSVILLE. de la Garza.
BROWNWOOD. Gayden.
BRYAN. W. A. Rees.
CAMERON. Newton.
CANYON. C. A. Murray.
COLLEGE STATION. F. Ayres, Binney, A. A. Blumberg, Halperin, McKee, W. L. Porter.
DALLAS. Dice, Hartsfield, Hosford, E. H. Jones, Mahoney, Reinsch.
DENTON. M. C. Brown.
EDINBURG. A. B. Horton.
FORT WORTH. Estes, Howard, E. R. Tucker.
GALVESTON. P. H. Underwood.
GEORGETOWN. Wapple.
HOUSTON. Bray, Dean, G. C. Evans, Ewing, L. R. Ford, Hickey, E. O. Lovett.
LUBBOCK. Chaney, Lyle, Michie, Moursund, P. K. Rees, L. V. Robinson, Sparks, E. T. Stafford, R. S. Underwood, Wait, Whyburn.
MILFORD. Durham.
NACOGDOCHES. C. E. Ferguson.
PENELOPE. Christian.
RANGER. E. C. Kennedy.
SAN ANTONIO. Klipple, McNelly, J. E. Nelson, Udinski.

SAN MARCOS. Sewell.
SEMINARY HILL. Hendricks.
SHERMAN. May.
STEPHENVILLE. McSweeny, Marrs, Redden.
TYLER. W. A. Nelson.
WACO. Harrell.
WICHITA FALLS. B. T. Adams, Shirley.

UTAH. (5)

SALT LAKE CITY. J. L. Gibson, Horsfall, Pehrson, Stevenson, Unseld.

VERMONT. (8)

BURLINGTON. Butterfield, Donahue, Millington, Swift, E. Thomas.
MIDDLEBURY. Hazeltine, L. R. Perkins, E. E. Wiley.

VIRGINIA. (37)

ABINGDON. V. L. Wright.
ASHLAND. Blincoe, T. McN. Simpson.
BLACKSBURG. Brodie, Hatcher, O'Shaughnessy, J. E. Williams.
BRIDGEWATER. Shull.
CHARLOTTESVILLE. F. A. Wells.
CLIFTON STATION. O. Stone.
EAST RADFORD. Bowers.
EMORY. J. S. Miller.
FARMVILLE. C. B. Taliaferro.
HOLLINS. Dickinson.
LEXINGTON. Funkhouser, Paxton, L. W. Smith, C. W. Watts, Witt.
LYNCHBURG. E. M. Berry, Larew, Mauch, Pattillo.
MONTEREY. Colaw.
RICHMOND. Amig.
RICHMOND COLLEGE. Gaines.
SALEM. Carpenter.
SWEET BRIAR. Calkins, Morenus.
UNIVERSITY. W. H. Echols, Linfield, Luck, Sparrow, Thornton.
UNIVERSITY OF RICHMOND. I. Harris.
WILLIAMSBURG. Rowe, B. Russell.

WASHINGTON. (12)

EVERETT. Robb.
PULLMAN. Issacs.
SEATTLE. Ballantine, Jerbert, Moritz, Mullemeister, Neikirk, Winger.
SPOKANE. Buxton.
TACOMA. Hanawalt.
WALLA WALLA. Bratton.
YAKIMA. A. M. Whitney.

WEST VIRGINIA. (12)

FAIRMONT. M. E. McCarty.
HARPERS FERRY. Drew.
HUNTINGTON. Hackney.
INSTITUTE. Cox.
KENOVA. E. M. Henry.
MORGANTOWN. M. Buchanan, Colwell, Eiesland, R. M. Mathews, C. N. Reynolds, B. M. Turner.
WHEELING. Bagby.

WISCONSIN. (38)

BELOIT. H. H. Conwell, Fischer, Huffer.
LA CROSSE. Adkins, E. H. Snyder.
MADISON. F. E. Allen, Dancer, Dowling, Fowlkes, W. W. Hart, F. Hopkins, Ingraham, Langer, Mickelson, Roth, Skinner, Slichter, Van Vleck, Vass, W. Weaver.
MILTON. A. E. Whitford.
MILWAUKEE. Bear, E. R. Beckwith, Bunyan, Ericson, P. H. Evans, Knight, Levandowski, Parkinson, Pettit, Quarles, C. G. Simpson.
PLATTEVILLE. Warner.
RIPON. Woodmansee.
SUPERIOR. C. W. Smith.
WAUPUN. Hein.
WEST DE PERE. DeCleene.
WISCONSIN RAPIDS. McMillan.

WYOMING. (5)

LARAMIE. Barr, Bellamy, Fitterer, Neubauer, Rechard.

FOREIGN MEMBERS. (Other than Canada.)

ARGENTINE. (1)

BUENOS AIRES. Baidaff.

BELGIUM. (2)

BRUSSELS. Sauté.
LIEGE. Van Hee.

CHINA. (7)

CANTON. W. E. MacDonald.
CHANGSHA. Lao, Leavens.
NANSIANG. Loh.
PEKING. Konantz.
SHANGHAI. Ely.
TANGSHAN. Patten.

FRANCE. (4)

NANCY. Gérardin.
PARIS. Borel, Hadamard.
STRASBOURG. Fréchet.

GERMANY. (1)

MUNICH. Wieleitner.

GREAT BRITAIN. (5)

CAMBRIDGE. P. W. Wood.
EDINBURGH. Horsburgh.
HOVE. Chepmell.
OXFORD. Frecheville, Hardy.

INDIA. (2)

ALLAHABAD CITY. Mitra.
MADURA. Lockwood.

ITALY. (6)

BOLOGNA. Bortolotti, Enriques, Pincherle.
PISA. Bianchi.
ROME. Laboccetta.
TURIN. Fubini.

JAPAN. (2)
SENDAI. Hayashi.
TOKYO. Mikami.

NEW ZEALAND. (1)
DUNEDIN. Martyn.

POLAND. (1)
WARSAW. Dickstein.

PORTUGAL. (1)
LISBON. da Cunha.

SOUTH AFRICA. (3)
BLOEMFONTEIN. Arndt.
JOHANNESBURG. Dalton.
RONDEBOSCH. Muir.

SPAIN. (1)
MADRID. de Toledo.

SWITZERLAND. (3)
FRIBOURG. Bays.
GENEVA. Fehr.
NEUCHATEL. DuPasquier.

SYRIA. (1)
BEIRUT. Jurdak.

TURKEY. (1)
CONSTANTINOPLE. Mourad.

UKRAINE. (1)
KIEFF. Kryloff.

RECAPITULATION OF MEMBERSHIP.

Individual members November 15, 1927	1,849	
Institutional members November 15, 1927	127	
Total membership November 15, 1927		1,976
Total membership November 15, 1925		1,874

CHARTER MEMBERSHIP

Individual charter members	1,045	
Institutional charter members	52	
Total charter membership		1,097
Net gain in individual members	804	
Net gain in institutional members	75	
Total net gain over charter membership		879
Total net gain since November 15, 1925		102

BY-LAWS OF THE MATHEMATICAL ASSOCIATION OF AMERICA (INCORPORATED).

ARTICLE I—NAME, PURPOSE AND CORPORATE SEAL.

1. This organization shall be known as

THE MATHEMATICAL ASSOCIATION OF AMERICA (INCORPORATED).

2. Its object shall be to assist in promoting the interests of mathematics in America, especially in the collegiate field, by holding meetings in any part of the United States or Canada for the presentation and discussion of mathematical papers, by the publication of mathematical papers, journals, books, monographs and reports, by conducting investigations for the purpose of improving the teaching of mathematics, by accumulating a mathematical library and by coöperating with other organizations whenever this may be desirable for attaining these or similar objects.

3. The Corporate Seal of the Association shall have inscribed thereon the name of the Association and the words "Corporate Seal—Illinois."

ARTICLE II—MEMBERSHIP.

1. Any person who is interested in the field of collegiate mathematics shall be eligible for election to membership in the Association.

2. Any institution in which the Calculus is regularly taught shall be eligible for election to institutional membership in the Association. Such an institution shall have the privilege of sending a voting delegate to the meetings of the Association.

3. Election to membership shall be by vote of the Board upon written application from the individual or institution seeking admission, endorsed in the case of individuals by two members of the Association.

4. Those who were admitted to membership in The Mathematical Association of America (unincorporated) prior to October 1, 1920, and were in good standing as such on that date, were thereby admitted to membership in this Association (Incorporated).

ARTICLE III—BOARD OF TRUSTEES AND OFFICERS.

1. The Officers of the Association shall be a President, two (2) Vice-Presidents, a Secretary-Treasurer, a Librarian and three (3) members of a Committee on Official Journal.

2. The control and management of the affairs and funds of the Association shall be vested in a Board of twenty (20) Trustees (hereinafter called the "Board"), who shall be members of the Association. This Board shall consist of the officers of the Association and twelve (12) additional members.

3. The President shall be elected by the Association's members biennially for a term of two years and shall be ineligible for reëlection. The Vice-Presidents shall be elected by the Association's members annually for a term of one year, and four members of the Board shall be elected by the Association's members annually for a term of three years. They shall be eligible for reëlection, but not for more than two (2) consecutive terms. The Secretary-Treasurer, the Librarian, and the Committee on Official Journal, consisting of the Editor-in-Chief, the Manager and one other member, shall be appointed by the Board. All Officers and other Trustees shall hold over until their respective successors are elected or appointed and qualify.

4. The Board shall transact the official business of the Association and shall report its actions at the annual business meeting of the Association and in the official journal. A statement regarding any proposed action of the Board which makes or alters a question of policy shall be published in the official journal, or notice of such proposed action shall be mailed to each member, before final action has been taken, so that members of the Association may make known to the Board their individual views.

5. The Board shall have authority to fill vacancies *ad interim* in any office, including vacancies in the Board and in the Committee on Official Journal, and to make any other appointments necessary for the transaction of the business of the Association.

6. At all meetings of the Board of Trustees a quorum shall consist of not less than five (5) members and no business may be validly transacted at a meeting at which less than a quorum is present; *provided* that any meeting of the Board, whether or not a quorum be present, may be adjourned to a specified time and place by a majority of the members present without notice to the members at large other than announcement at such meeting. Informal action based on a mail ballot by the members of the Board, if ratified at a properly convened meeting of the Board, shall be as valid and effective as if originally authorized at such meeting.

7. Approximately two months before the date of the annual meeting all members shall be given an opportunity to nominate by mail a candidate for each office to be filled by the members

for the ensuing year. Approximately one month before the annual meeting the Board shall announce two candidates for each office to be filled by the members, one being the person who received the highest vote in the nominations and the other being selected from among the several nominees next in order. The election shall be by mail or in person and shall close on the day of the annual meeting.

8. The President shall be the Executive Officer of the Association, shall preside at all meetings of the Board of Trustees and at the annual meeting of the Association. He shall have the usual duties pertaining to his office and such other duties as may from time to time be assigned him by the Board of Trustees.

9. The Vice-Presidents shall, in the absence of the President, have and exercise the powers of the President, their order being determined alphabetically. The Board of Trustees may assign to the Vice-Presidents such duties as may from time to time be determined.

10. The Secretary-Treasurer shall have the usual duties pertaining to the Office of Secretary and of Treasurer, including the custody of the records of the Association and of its Corporate Seal, the keeping of minutes of the meetings of the Board of Trustees and of the annual meeting and special meetings of members, and giving of due notice of all regular and special meetings of the Association and of the Board of Trustees and the supervision and safe-keeping of the funds of the Association. The Secretary-Treasurer shall also have the duty of seeing that whenever Trustees are elected, including the election of Trustees to fill vacancies, a Certificate, under the Seal of the Association, giving the names of those elected and the term of their office, shall be recorded in the Office of the Recorder of Deeds for Cook County, Illinois. Such Certificate shall be signed by the Secretary-Treasurer and verified by oath of the President.

11. The Committee on Official Journal shall have supervision of the official journal subject to the control of the Board of Trustees.

12. The Librarian shall have general charge of the library of the Association and shall direct its affairs, including the exchange of the publications of the Association, subject to the control of the Board.

Article IV—Meetings.

1. A meeting of the Association shall be held annually, at such time and place as the Board may direct. Special meetings of the Association may be called from time to time by the Board, or while the Board is not in session by the President of the Association, to be held at such time and place as may appear from the call.

2. The outgoing Board shall hold a meeting immediately preceding the annual meeting of the Association next succeeding their election, and the members of the new Board shall hold a meeting and organize, by completing the Board, immediately succeeding the annual meeting of the Association at which the new members thereof were elected. Further meetings of the Board may be held from time to time at the call of the President or of any three (3) members of the Board.

3. Notice of any meeting of members of the Association shall be given by the Secretary-Treasurer at least thirty (30) days prior to the date set for each meeting. Notice of all meetings of the Board other than the regular meetings provided in Section 2 shall be given to each member of the Board at least fifteen (15) days prior to the date set therefor.

4. Any member of the Association or of the Board may waive notice with the same effect as if due notice had been given him.

5. At all meetings of the Association a quorum shall consist of not less than twenty-five (25) members and no business may be validly transacted at a meeting at which less than a quorum is present; *provided* that any meeting of the Association, whether or not a quorum be present, may be adjourned to a specified time and place by a majority of the members present without notice to the members at large other than the announcement at such meeting.

6. Members may take part and vote in person or by proxy at all meetings of the Association.

Article V—Sections.

1. Any group of not less than ten (10) members of this Association may petition the Board for authority to organize a Section of the Association for the purpose of holding local meetings. The Board shall have power to specify the conditions under which such authority shall be granted.

2. The Association shall not be obligated to pay from its treasury any of the expenses of such Sections.

Article VI—Official Publications.

1. The Association shall publish an official journal, which shall be sent free to all members of the Association in accordance with Article VII.

2. The Board shall have full control of the publication and sale of the official journal and of all other official publications.

3. The official journal shall be under the general management of the Committee on Official Journal. There shall also be appointed by the Board a body of Associate Editors who shall give assistance in connection with the official journal and under the direction of the Committee on Official Journal.

4. The Board shall from time to time, as the need arises, make special provision for the management of any other official publications.

5. The Board shall fix the price of the official journal and of any other official publications of the Association, but in no case shall the journal be sold to non-members for less than the annual dues of individual members.

ARTICLE VII—DUES.

1. Individual members of the Association shall pay an initiation fee of Two Dollars ($2) at the time of election.

2. The annual dues of each individual member shall be Four Dollars ($4), including a subscription to the official journal.

3. The annual dues of each institutional member shall be Seven Dollars ($7), including two (2) subscriptions to the official journal.

4. All dues shall be payable on the first of January of each year. Should the annual dues of any member remain unpaid beyond a reasonable time, his name shall be dropped from the list after due notice.

5. New members entering the Association after April 1 of any year shall have their dues prorated for the balance of the year, except when they desire to receive the full current volume of the official journal.

6. The life membership fee shall be the present value, according to McClintock's Male Annuitant Table based upon four (4) per cent interest, of an annuity due of Four Dollars ($4) a year at the attained age of the member; an annual valuation of the life membership fund shall be made under the McClintock Male Four (4) Per Cent Table; and the reserve thus computed shall be held as a liability.

ARTICLE VIII—AMENDMENTS TO THE ARTICLES OF ASSOCIATION AND BY-LAWS.

1. Changes in the Articles of Association or amendments to the By-Laws may be made at any annual meeting of the Association, or at any adjourned session thereof, or at any special meeting of the Association called for such purpose, by a two-thirds ($\frac{2}{3}$) vote of those present and entitled to vote; *provided* that due notice concerning such amendment shall have been printed in the official journal, or mailed to each member, at least one (1) month before the date of such meeting.

2. No changes in the Articles of Association shall have legal effect until a certificate thereof, verified by oath of the President and under Seal of the Association, attested by the Secretary-Treasurer, shall be filed in the office of the Secretary of State of the State of Illinois and recorded in the office of the Recorder of Deeds for Cook County, Illinois.

PERIODS OF SERVICE OF THE OFFICERS OF THE ASSOCIATION.

PRESIDENTS.

E. R. HEDRICK 1916
FLORIAN CAJORI 1917
E. V. HUNTINGTON 1918
H. E. SLAUGHT 1919
D. E. SMITH 1920
G. A. MILLER 1921
R. C. ARCHIBALD 1922
R. D. CARMICHAEL 1923
H. L. RIETZ 1924
J. L. COOLIDGE 1925
DUNHAM JACKSON 1926
W. B. FORD 1927–1928

VICE-PRESIDENTS.

E. V. HUNTINGTON 1916
G. A. MILLER 1916
D. N. LEHMER 1917, 1918
OSWALD VEBLEN 1917
J. W. YOUNG 1918, 1926
R. G. D. RICHARDSON 1919
H. L. RIETZ 1919
HELEN A. MERRILL 1920
E. J. WILCZYNSKI 1920
R. C. ARCHIBALD 1921
R. D. CARMICHAEL 1921, 1922
B. F. FINKEL 1922
A. B. CHACE 1923
L. P. EISENHART 1923
J. L. COOLIDGE 1924
DUNHAM JACKSON 1924, 1925
A. A. BENNETT 1925
W. B. FORD 1926
A. J. KEMPNER 1927
CLARA E. SMITH 1927

SECRETARY-TREASURER.

(Appointed by the Trustees after 1918)

W. D. CAIRNS 1916–

COMMITTEE ON PUBLICATIONS.

(Appointed by the Trustees.)

H. E. SLAUGHT 1916–
R. D. CARMICHAEL 1916–1918
W. H. BUSSEY 1916–1918
R. C. ARCHIBALD 1919–1921
W. A. HURWITZ 1919–1921
A. A. BENNETT 1922
H. P. MANNING 1921–1922
W. B. FORD 1923–1925
J. L. COOLIDGE 1923
A. J. KEMPNER 1924–
W. H. BUSSEY 1926–

ELECTED MEMBERS OF THE COUNCIL OR BOARD.

D. N. LEHMER 1916–1918, 1922–1924
R. E. MORITZ 1916–1918
K. D. SWARTZEL 1916
OSWALD VEBLEN 1916, 1920–1922, 1926–
R. C. ARCHIBALD 1916–1917, 1923–
FLORIAN CAJORI 1916, 1918–1923, 1926–
M. B. PORTER 1916–1917
J. W. YOUNG 1916–1917, 1920–1922
B. F. FINKEL 1916–1921
E. H. MOORE 1916–1921, 1923–
ALEXANDER ZIWET 1916–1918
E. R. HEDRICK 1917–1922, 1924–
J. N. VAN DER VRIES 1916–1918
HELEN A. MERRILL 1917–1919
D. E. SMITH 1917–1919, 1921–1926
ELIZABETH B. COWLEY 1918–1920
G. A. MILLER 1918–1920, 1922–1924
E. J. WILCZYNSKI 1918–1919, 1922–1926
L. P. EISENHART 1919–1922, 1925–
E. V. HUNTINGTON 1917, 1919–
E. L. DODD 1920
R. D. CARMICHAEL 1920, 1924–
A. A. BENNETT 1921
H. L. RIETZ 1921–1923, 1925–
C. F. GUMMER 1921–1925
DUNHAM JACKSON 1923–
CLARA E. SMITH 1923–1925
A. B. CHACE 1924–1925
J. L. COOLIDGE 1926–
E. T. BELL 1927–

The Carus Mathematical Monographs

The CARUS MONOGRAPHS are already fulfilling their mission as intended by the generous donor, MRS. MARY HEGELER CARUS and her son, DR. EDWARD H. CARUS.

Somewhat more than one-half the members of the Association have taken advantage of this distribution at cost of the first three Monographs already published. Those who neglected to do so at the start may still have the privilege by applying to the Secretary. Each member is entitled to one copy of each Monograph at this special price.

It would be a great tribute to the donor and an honor to the Association if a large majority of the members would subscribe for the complete series.

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MONOGRAPHS THUS FAR PUBLISHED

No. 1. *Calculus of Variations*, by PROFESSOR G. A. BLISS. (First Impression in 1925, Second Impression in 1927.)

No. 2. *Analytic Functions of a Complex Variable*, by PROFESSOR D. R. CURTISS. (First Impression, 1926.)

No. 3. *Mathematical Statistics*, by PROFESSOR H. L. RIETZ. (First Impression, March, 1927.)

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